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Sarh et al.

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(45) **Date of Patent: Apr. 21, 2015**

(54) **ELECTROMAGNETIC CRAWLER ASSEMBLY SYSTEM**

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(73) Assignee: **The Boeing Company**, Chicago, IL (US)

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(22) Filed: **Mar. 16, 2014**

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Related U.S. Application Data

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(51) **Int. Cl.**

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B23Q 7/04	(2006.01)
B23Q 9/02	(2006.01)
B62D 57/024	(2006.01)
B64F 5/00	(2006.01)
B23Q 9/00	(2006.01)

(52) **U.S. Cl.**
CPC ***B23Q 9/02*** (2013.01); ***B62D 57/024*** (2013.01); ***B64F 5/0009*** (2013.01); ***B23Q 9/0042*** (2013.01)

(58) **Field of Classification Search**
CPC B62D 57/00; B62D 57/02; B62D 57/022; B62D 57/024; B62D 57/032; B21D 43/18
USPC 29/50–56.56, 429, 428, 430, 431, 565, 29/283, 407.09, 281.1; 180/8.1, 8.5, 8.6, 180/164; 414/749.1, 735; 114/222; 606/1, 606/2, 41
See application file for complete search history.

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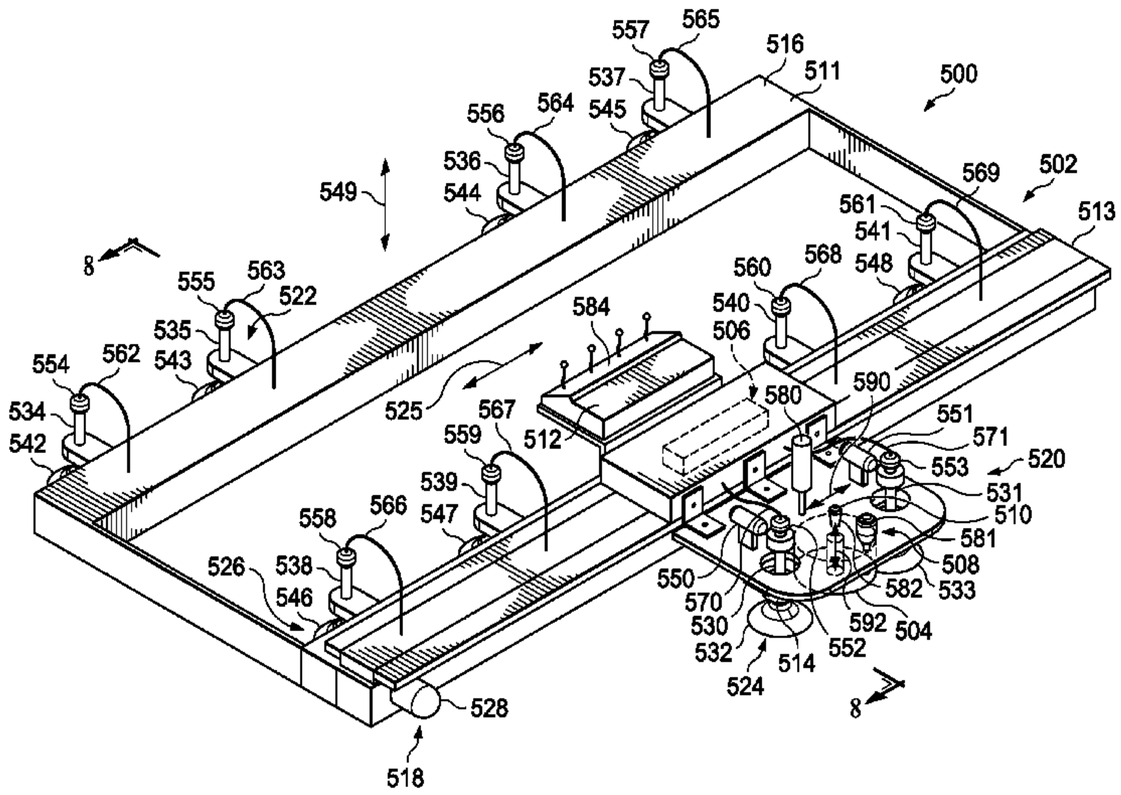
Primary Examiner — Richard Chang
(74) *Attorney, Agent, or Firm* — Yee & Associates, P.C.

(57) **ABSTRACT**

A method and apparatus for performing operations on a workpiece. A first frame in a frame system may be held on the workpiece by applying a vacuum to the first frame. A second frame in the frame system may be detached from the workpiece by applying a pressure to the second frame. The second frame may be moved to a location on the workpiece. The second frame may be attached to the workpiece by applying the vacuum to the second frame. An operation may be performed on the workpiece.

16 Claims, 13 Drawing Sheets



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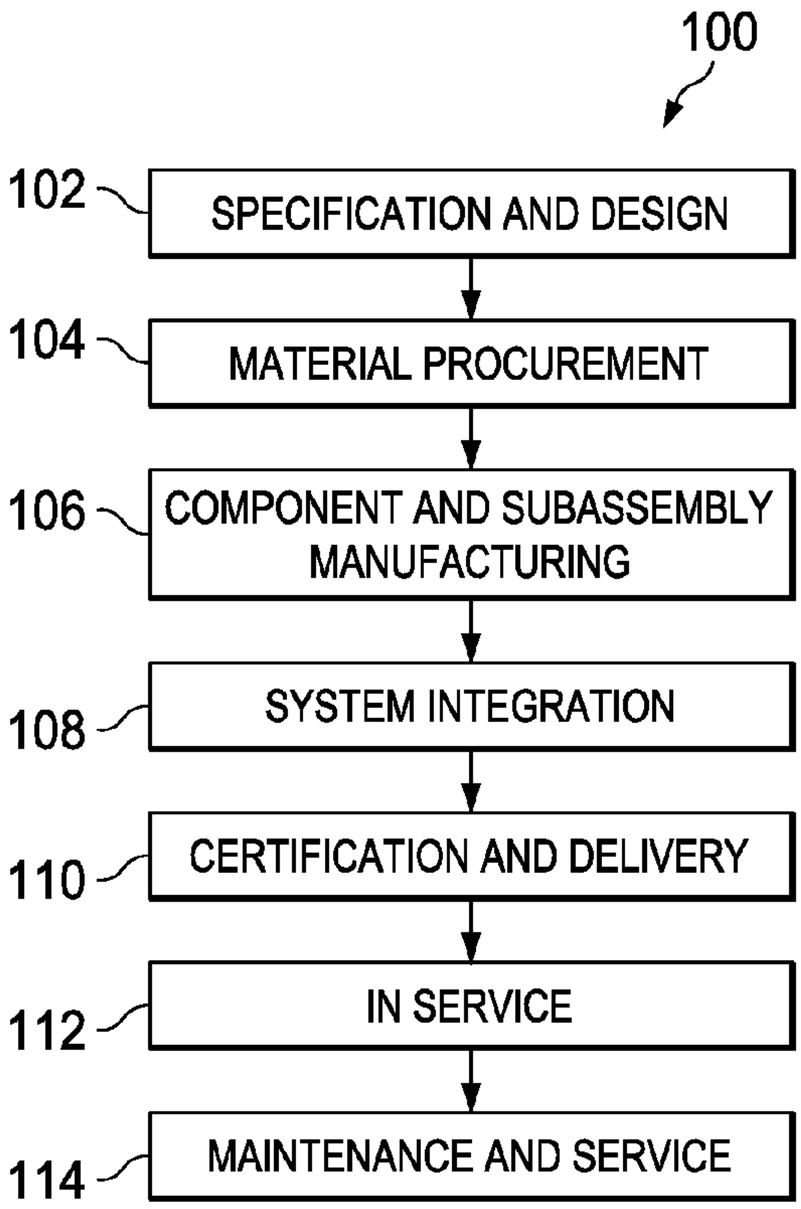

100
102
SPECIFICATION AND DESIGN
104
MATERIAL PROCUREMENT
106
COMPONENT AND SUBASSEMBLY MANUFACTURING
108
SYSTEM INTEGRATION
110
CERTIFICATION AND DELIVERY
112
IN SERVICE
114
MAINTENANCE AND SERVICE

FIG. 1

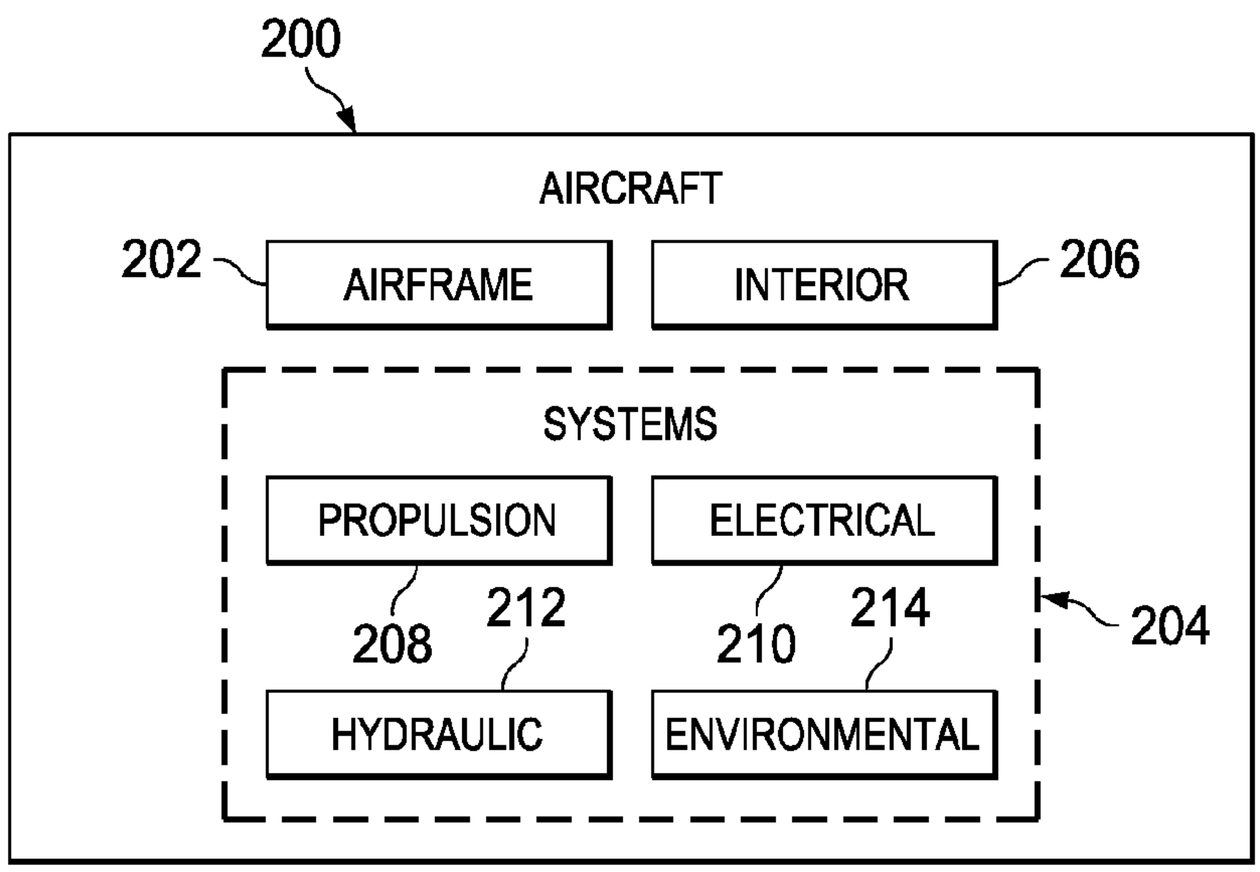

200
AIRCRAFT
202
AIRFRAME
INTERIOR
206
SYSTEMS
PROPULSION
ELECTRICAL
208
212
210
214
204
HYDRAULIC
ENVIRONMENTAL

FIG. 2

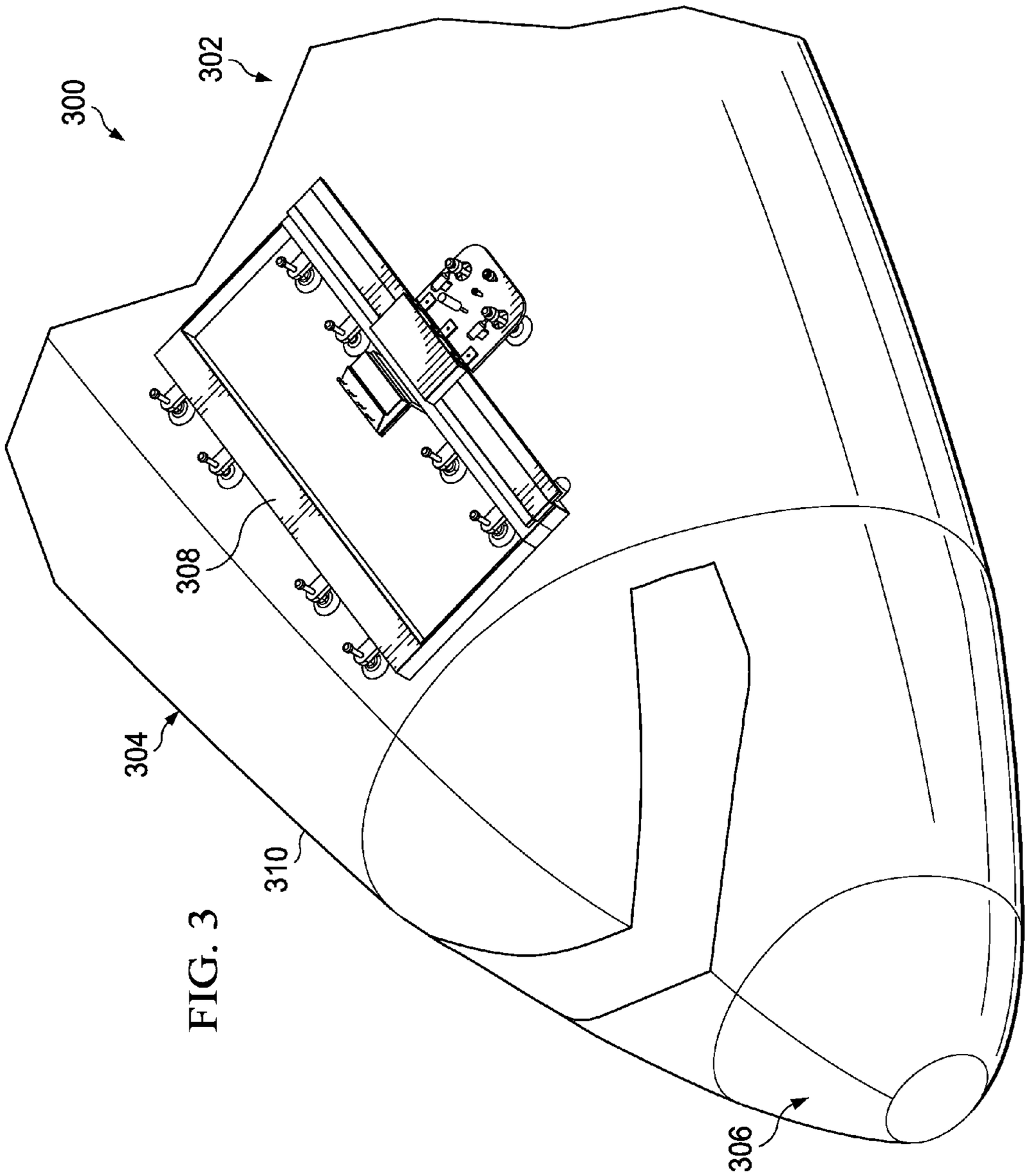
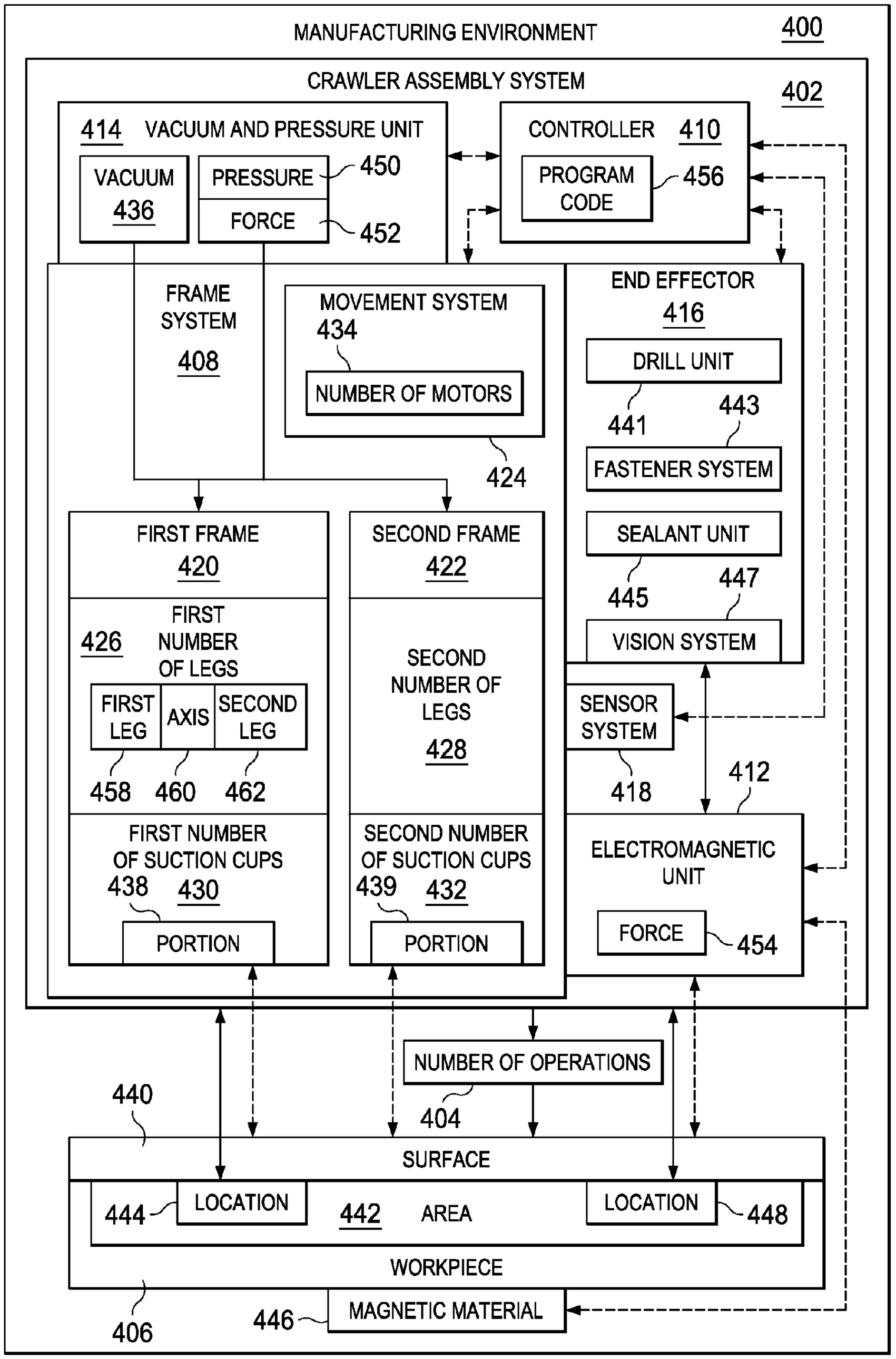


FIG. 3

FIG. 4


MANUFACTURING ENVIRONMENT
400
CRAWLER ASSEMBLY SYSTEM
402
414 VACUUM AND PRESSURE UNIT
VACUUM 436
PRESSURE
450
FORCE
452
CONTROLLER 410
PROGRAM CODE
456
FRAME SYSTEM 408
MOVEMENT SYSTEM 434
NUMBER OF MOTORS
424
END EFFECTOR 416
DRILL UNIT
441
443
FASTENER SYSTEM
SEALANT UNIT
445
447
VISION SYSTEM
FIRST FRAME 420
SECOND FRAME 422
426 FIRST NUMBER OF LEGS
FIRST LEG
AXIS
SECOND LEG
458
460
462
SECOND NUMBER OF LEGS 428
SENSOR SYSTEM
418
412
FIRST NUMBER OF SUCTION CUPS 438 430
PORTION
SECOND NUMBER OF SUCTION CUPS 439 432
PORTION
ELECTROMAGNETIC UNIT
FORCE
454
NUMBER OF OPERATIONS
404
440
SURFACE
444
LOCATION
442 AREA
LOCATION
448
WORKPIECE
406
446
MAGNETIC MATERIAL

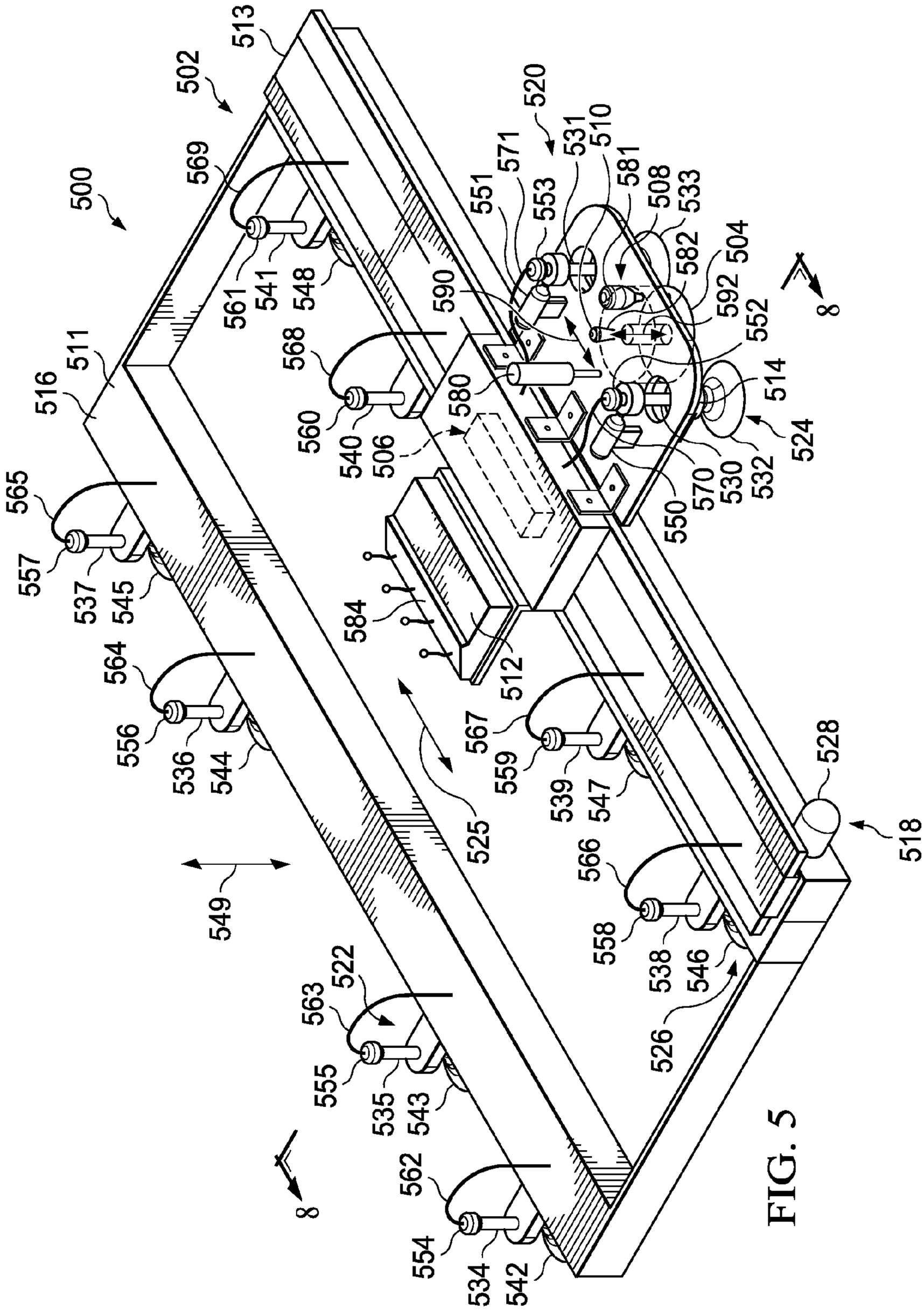

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FIG. 5

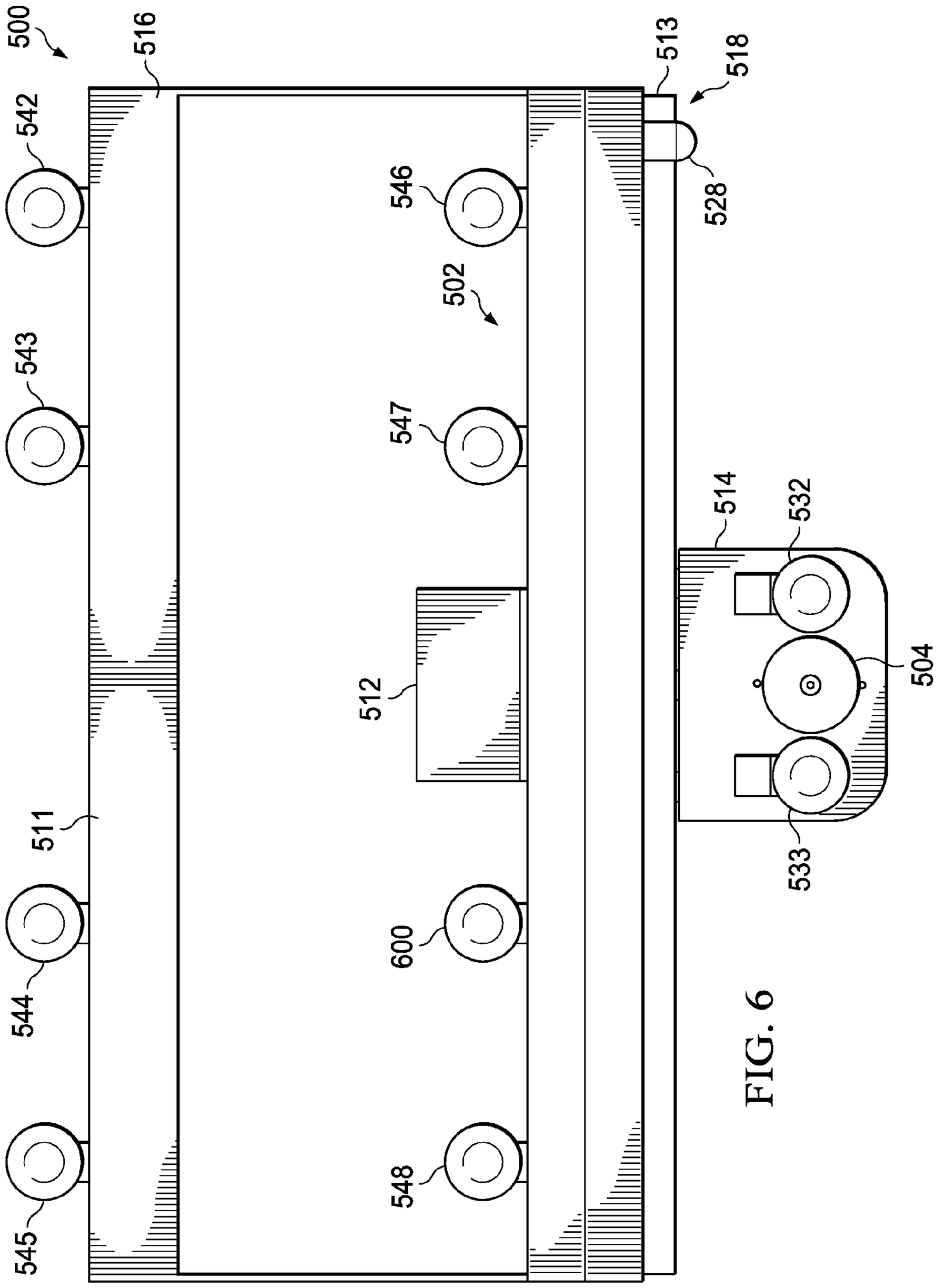
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FIG. 6

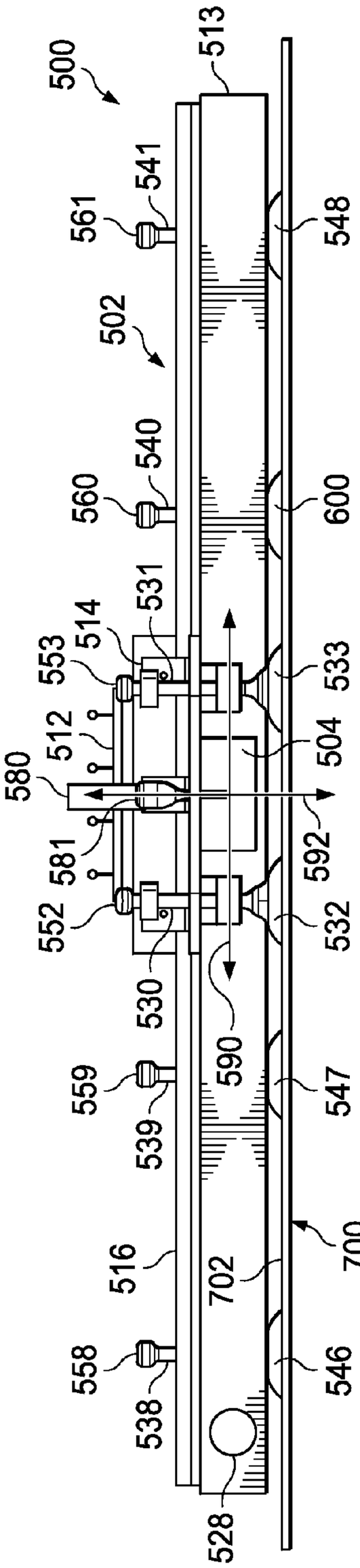
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FIG. 7

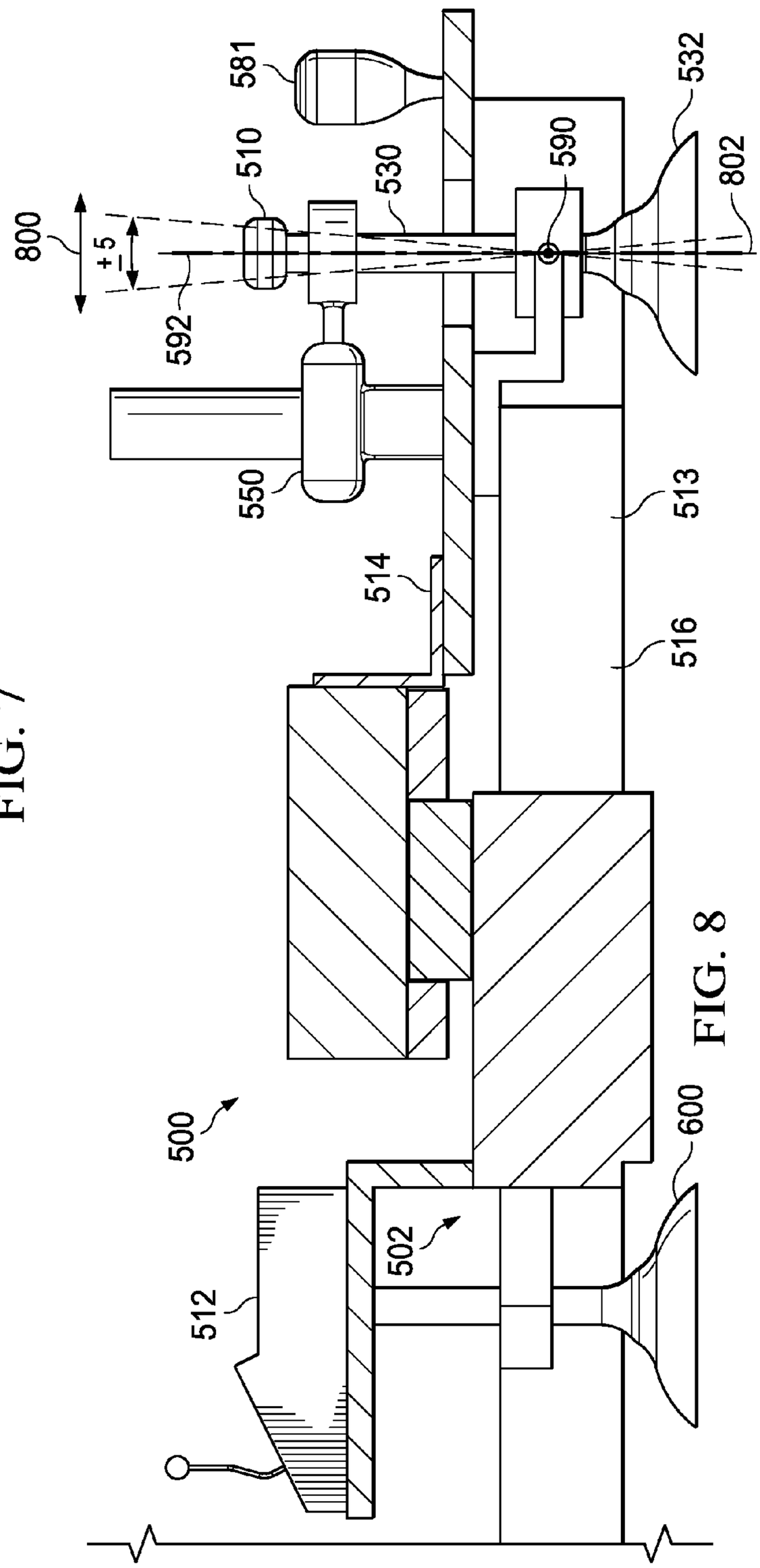
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FIG. 8

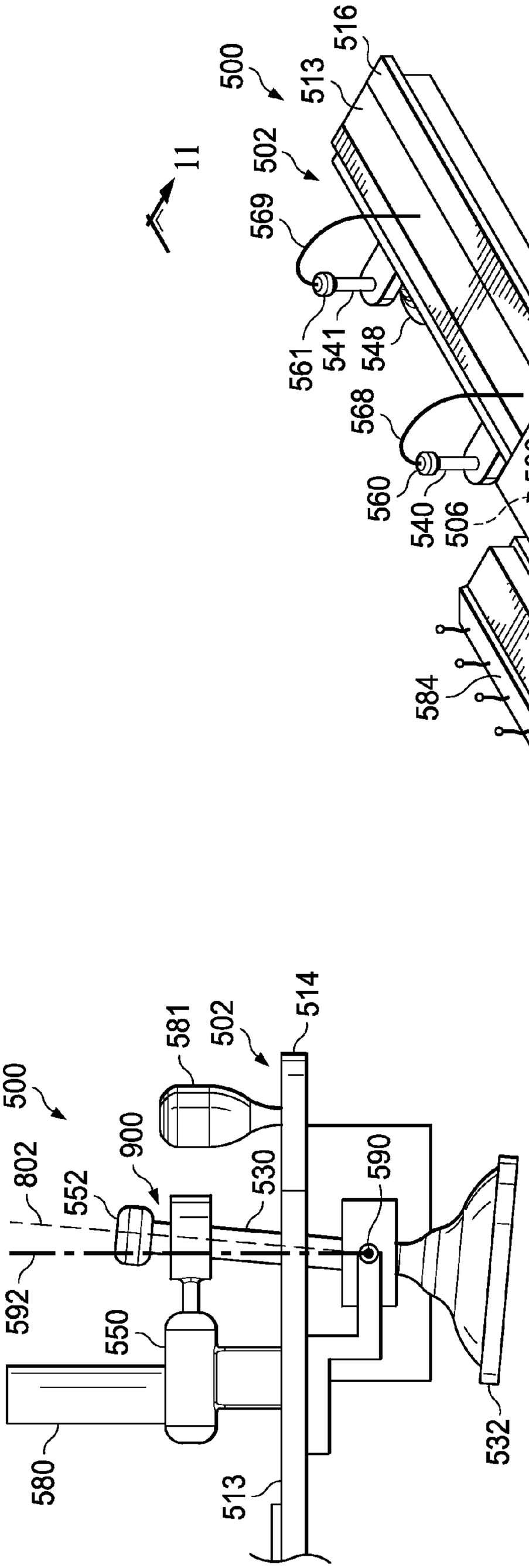
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FIG. 9

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FIG. 10

FIG. 11

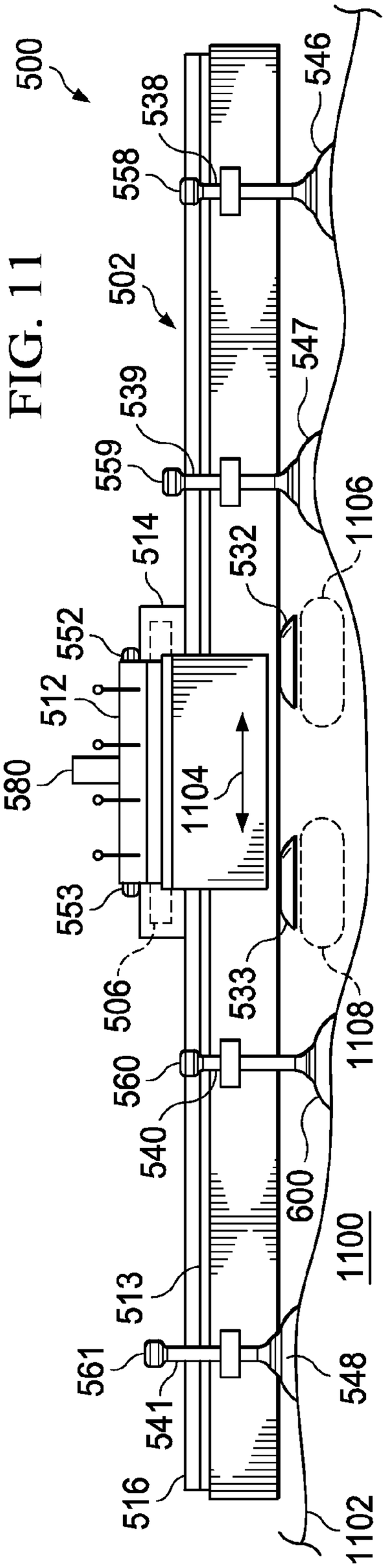
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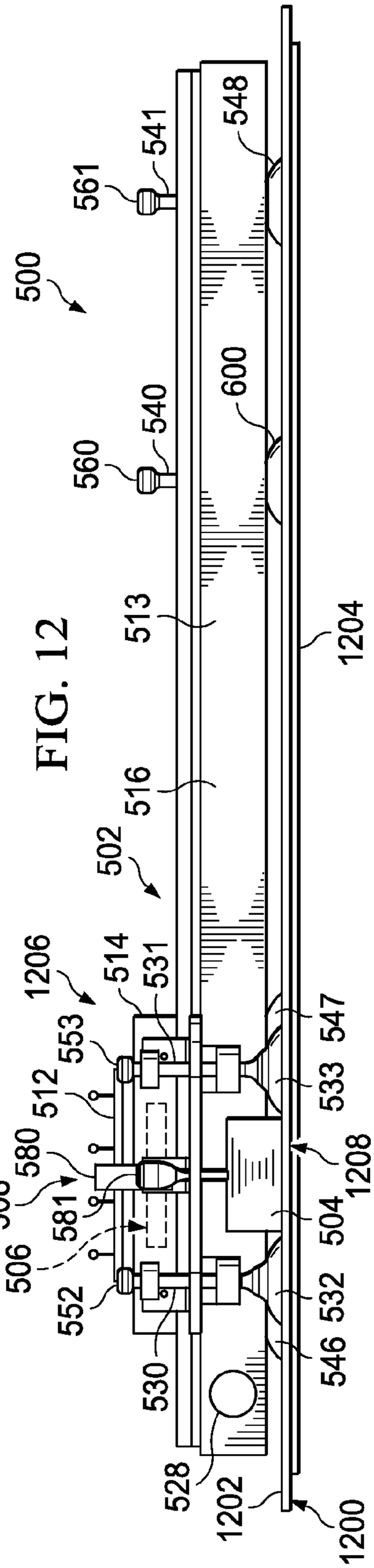
FIG. 12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1202
1200

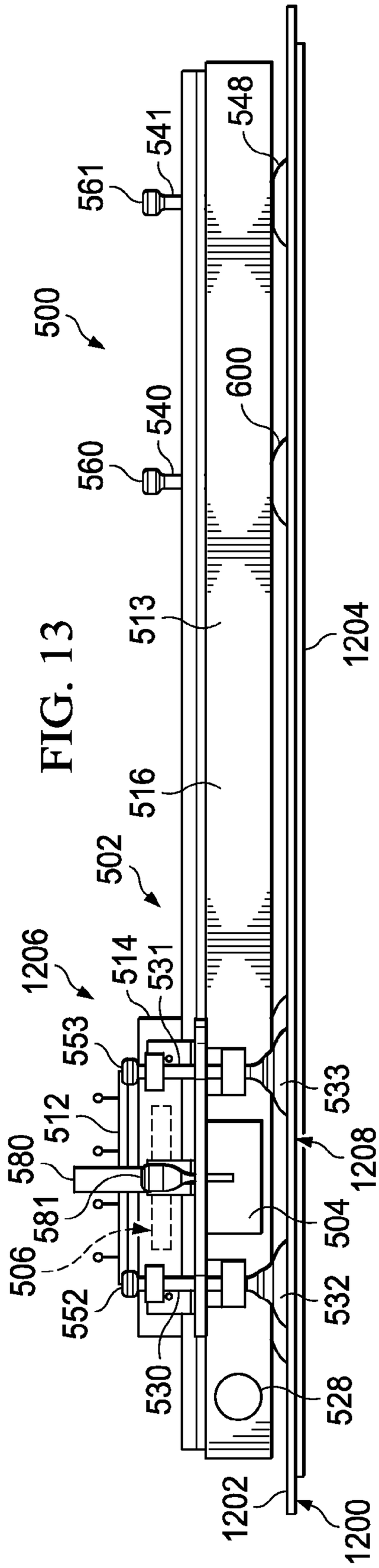
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FIG. 13

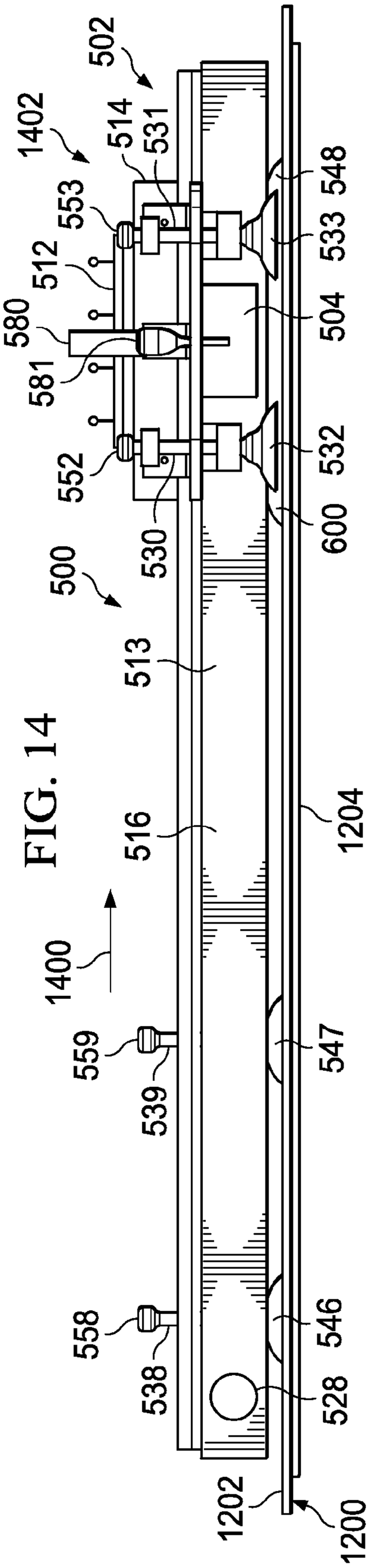
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FIG. 14

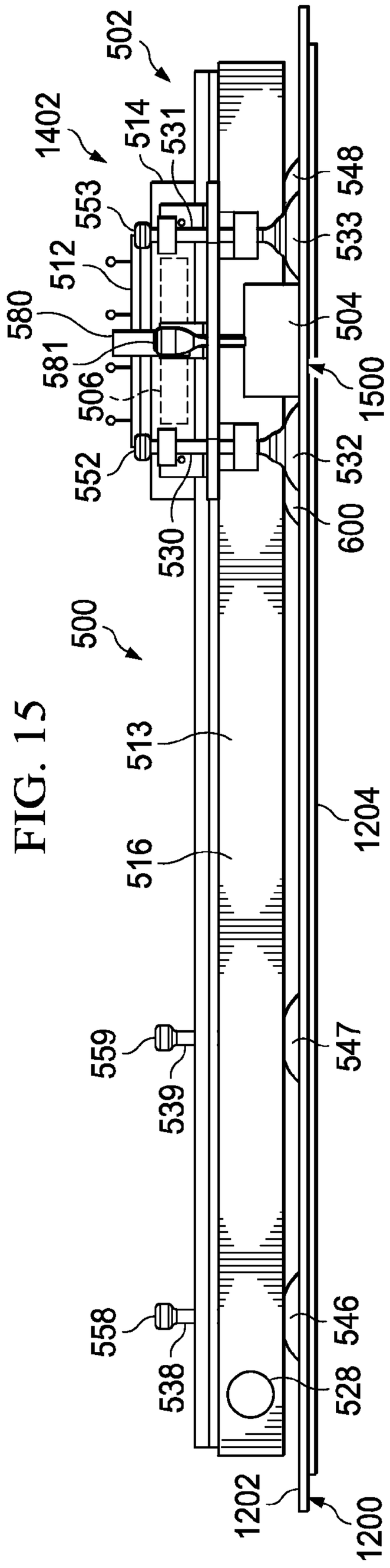
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FIG. 15

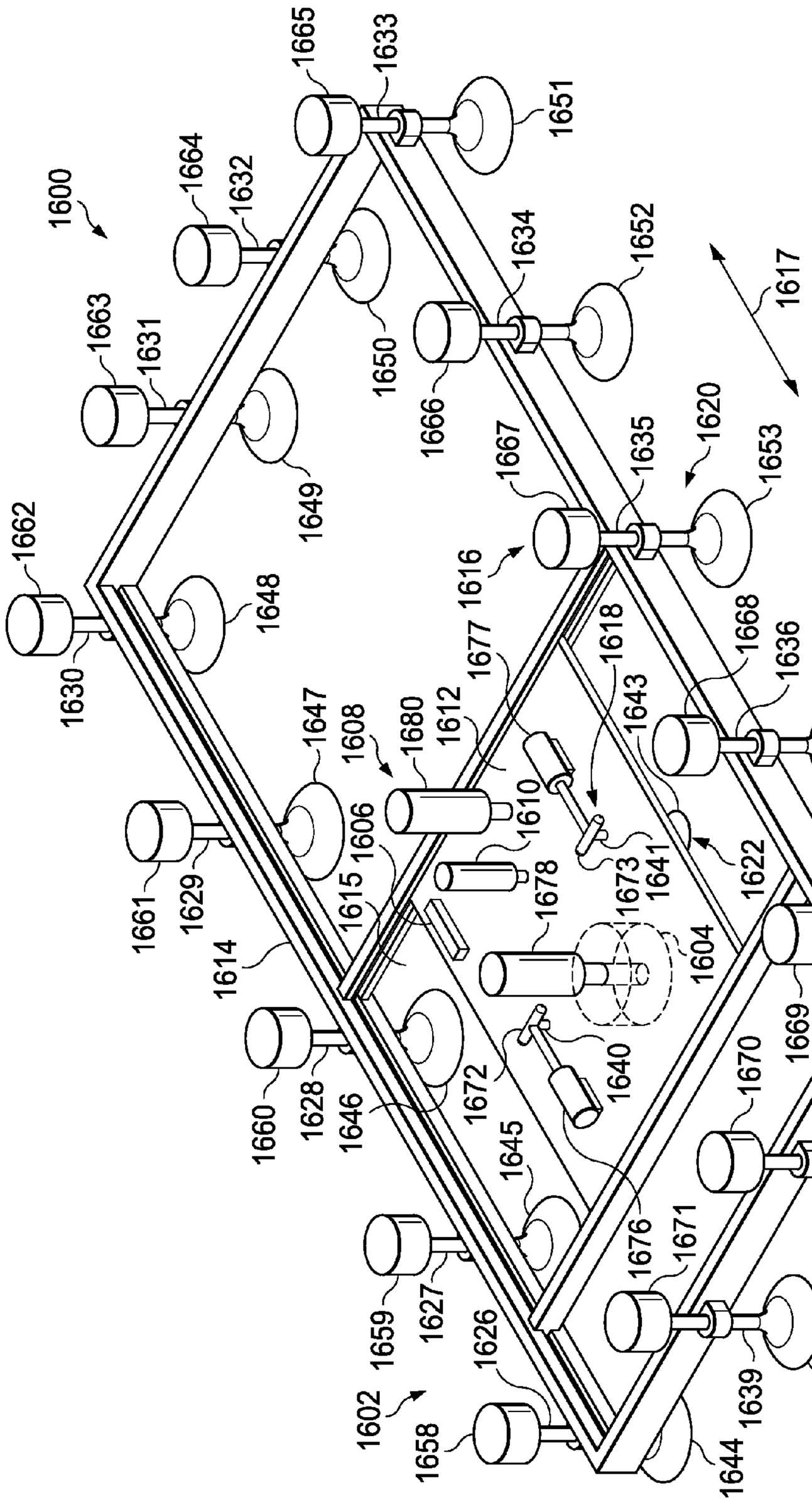
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FIG. 16

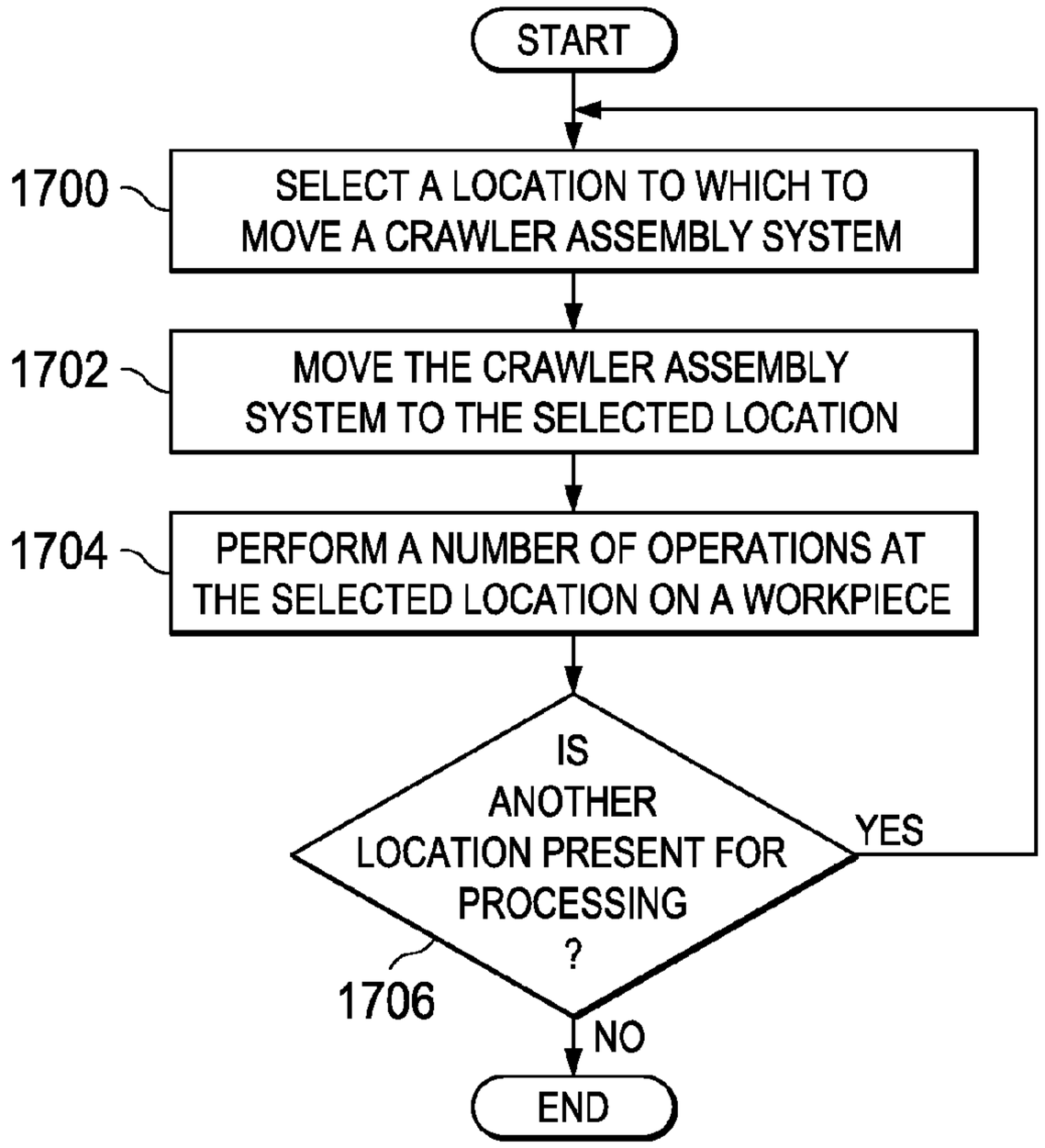
START
1700
SELECT A LOCATION TO WHICH TO MOVE A CRAWLER ASSEMBLY SYSTEM
1702
MOVE THE CRAWLER ASSEMBLY SYSTEM TO THE SELECTED LOCATION
1704
PERFORM A NUMBER OF OPERATIONS AT THE SELECTED LOCATION ON A WORKPIECE
IS ANOTHER LOCATION PRESENT FOR PROCESSING ?
1706
YES
NO
END

FIG. 17

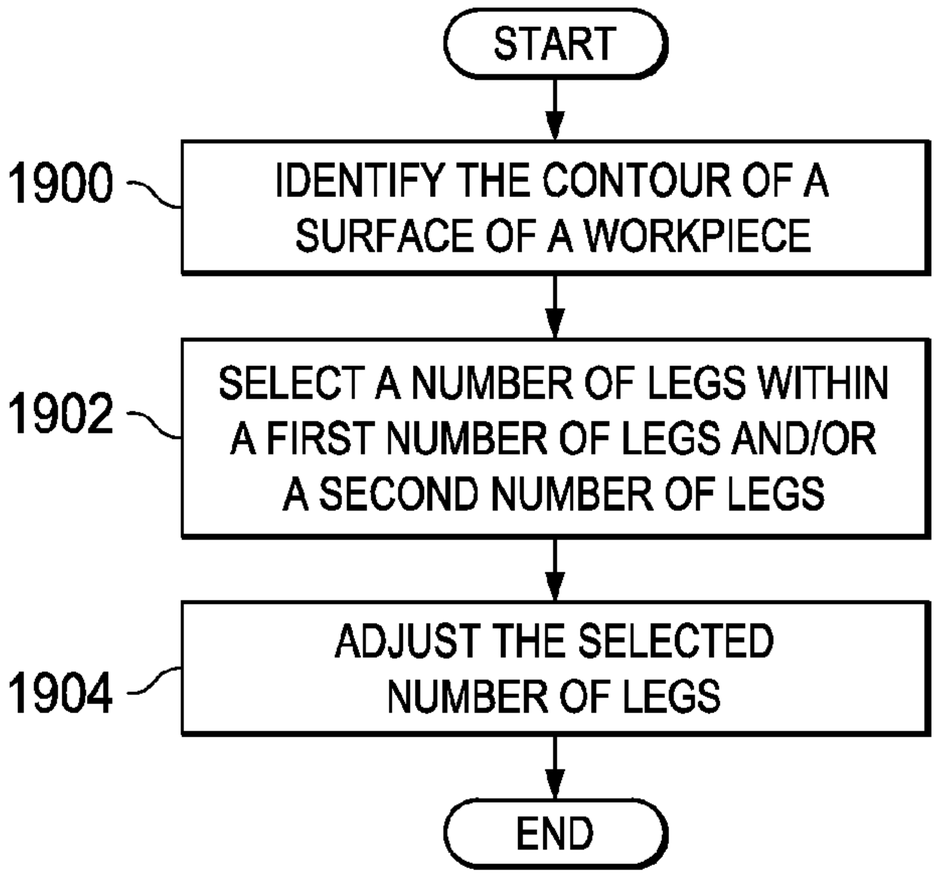
START
1900
IDENTIFY THE CONTOUR OF A SURFACE OF A WORKPIECE
1902
SELECT A NUMBER OF LEGS WITHIN A FIRST NUMBER OF LEGS AND/OR A SECOND NUMBER OF LEGS
1904
ADJUST THE SELECTED NUMBER OF LEGS
END

FIG. 19

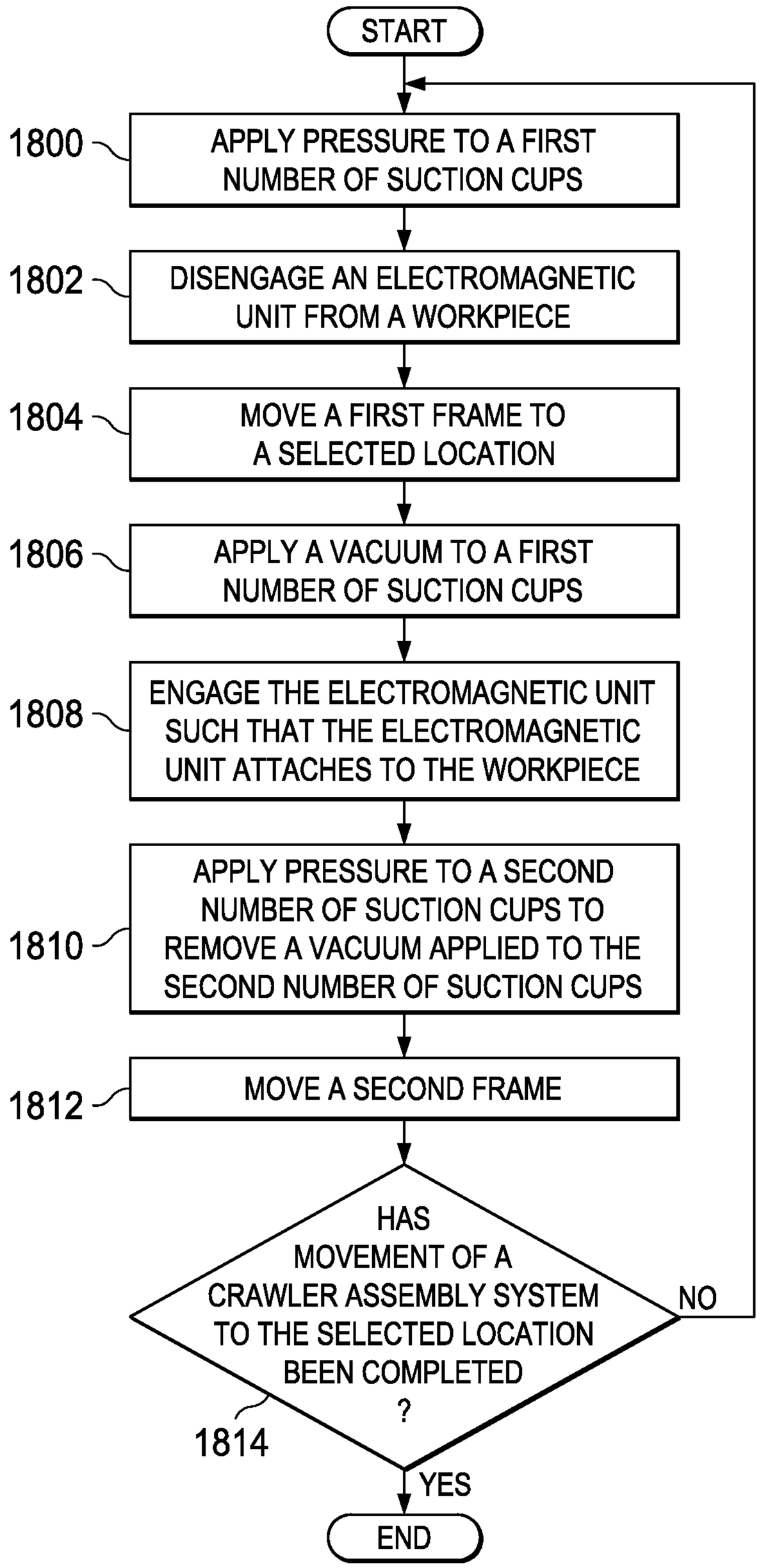
START
1800
APPLY PRESSURE TO A FIRST NUMBER OF SUCTION CUPS
1802
DISENGAGE AN ELECTROMAGNETIC UNIT FROM A WORKPIECE
1804
MOVE A FIRST FRAME TO A SELECTED LOCATION
1806
APPLY A VACUUM TO A FIRST NUMBER OF SUCTION CUPS
1808
ENGAGE THE ELECTROMAGNETIC UNIT SUCH THAT THE ELECTROMAGNETIC UNIT ATTACHES TO THE WORKPIECE
1810
APPLY PRESSURE TO A SECOND NUMBER OF SUCTION CUPS TO REMOVE A VACUUM APPLIED TO THE SECOND NUMBER OF SUCTION CUPS
1812
MOVE A SECOND FRAME
HAS MOVEMENT OF A CRAWLER ASSEMBLY SYSTEM TO THE SELECTED LOCATION BEEN COMPLETED ?
1814
NO
YES
END

FIG. 18

ELECTROMAGNETIC CRAWLER ASSEMBLY SYSTEM

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a divisional of application Ser. No. 12/838,616, filed Jul. 19, 2010, status allowed, the entire disclosure of which is incorporated by reference herein.

BACKGROUND INFORMATION

1. Field

The present disclosure relates generally to manufacturing and, in particular, to a method and apparatus for attaching parts to each other. Still more particularly, the present disclosure relates to a method and apparatus for attaching parts to each other using a fastening system.

2. Background

In manufacturing structures, different parts may be connected to each other to form the structures. Aircraft structures, such as the wing and fuselage of an aircraft, may be manufactured by attaching parts to each other. For example, without limitation, panels may be placed onto ribs to form a fuselage. Panels also may be attached onto spars and ribs to form a wing for the aircraft.

The attachment of these panels and other parts to each other may be performed by operators or computer-controlled machines. With operators, two operators may be located opposite to each other on a workpiece, such as a panel and a rib. The operators may install clamping devices to hold the parts together. Thereafter, a drill may be operated by one of the operators to create a hole. A rivet or other type of fastener may then be installed into the hole.

This type of process may be time consuming and expensive. Large computer-controlled machines may be used to drill holes and install fasteners to fasten the parts to each other.

In some cases, however, the shape of the structure and/or the location of fasteners may prohibit the use of these machines. In these cases, operators may still perform the drilling and fastener installation operations. As a result, depending on the design of the structure, the time and expense of installing fasteners may be greater than desired.

Therefore, it would be advantageous to have a method and apparatus that takes into account one or more of the issues discussed above, as well as other possible issues.

SUMMARY

In one advantageous embodiment, an apparatus may comprise a frame system and a controller. The frame system may have a first frame and a second frame in which the frame system may be configured to hold an end effector that is configured to perform a number of operations. The first frame and the second frame may be configured for attachment to a workpiece. The controller may be configured to control attachment of the first frame and the second frame to the workpiece by applying a vacuum and a pressure during movement of the frame system.

In another advantageous embodiment, a crawler assembly system may comprise a frame system, a first number of suction cups, a second number of suction cups, a controller, an electromagnetic unit, a vacuum and pressure unit, and an end effector. The frame system may be configured to hold an end effector that is configured to perform a number of operations on a workpiece. The frame system may comprise a first frame, a second frame, a first number of legs, a second number of legs, and a movement system. The first frame and the second frame may be configured to move relative to each other on the workpiece. A first leg in a first portion of the first number of legs may be configured to rotate about a first axis in a first direction. A second leg in a second portion of the first number of legs may be configured to rotate about the first axis in a second direction. Rotation of the first leg in the first direction and the second leg in the second direction about the first axis may cause rotation of the frame system about a second axis that is substantially perpendicular to a surface of the workpiece. The movement system may be configured to move the first frame and the second frame relative to each other. The movement system may be configured to move the first number of legs and the second number of legs to conform to the surface of the workpiece while the end effector is performing the number of operations on the workpiece. The first number of suction cups may be connected to the first frame by the first number of legs. The first number of suction cups may be configured for attachment to the workpiece. A first portion of the first number of suction cups may be connected to the first portion of the first number of legs, and a second portion of the first number of suction cups may be connected to the second portion of the first number of legs. The second number of suction cups may be connected to the second frame by the second number of legs. The second number of suction cups may be configured for attachment to the workpiece. The controller may be configured to control an application of a vacuum and a pressure by the first number of suction cups and the second number of suction cups during movement of the frame system. Movement of the first portion of the first number of legs in the first direction and movement of the second portion of the first number of legs in the second direction, while the vacuum is applied to the first portion of the first number of suction cups and to the second portion of the second number of suction cups and the pressure is applied to the second number of suction cups, may cause the frame system to turn on the surface of the workpiece. The electromagnetic unit may be associated with the first frame. The electromagnetic unit may be configured to attract a magnetic material associated with the workpiece such that the electromagnetic unit may hold the first frame on the workpiece. A channel may extend through the electromagnetic unit and may be configured to receive an end of the end effector and allow the end of the end effector to reach a surface of the workpiece. The vacuum and pressure unit may be connected to the first number of suction cups and the second number of suction cups. The vacuum and pressure unit may be configured to apply at least one of the vacuum and the pressure to the first number of suction cups and the second number of suction cups. The end effector may comprise at least one of a drill unit, a fastener system, a sealant unit, and a vision system.

In yet another advantageous embodiment, a method may be provided for performing operations on a workpiece. A first frame in a frame system may be held on the workpiece by applying a vacuum to the first frame. A second frame in the frame system may be detached from the workpiece by applying a pressure to the second frame. The second frame may be moved to a location on the workpiece. The second frame may be attached to the workpiece by applying the vacuum to the second frame. An operation may be performed on the workpiece.

In still yet another advantageous embodiment, a method may be provided for performing operations on a workpiece. A crawler assembly system may be moved from a first location to a second location. The crawler assembly system may comprise a frame system, a first number of suction cups, a second

number of suction cups, and a controller. The frame system may have a first frame and a second frame in which the frame system may be configured to hold an end effector that may be configured to perform a number of operations. The first number of suction cups may be associated with the first frame by a number of legs. The first number of suction cups may be configured for attachment to the workpiece. The second number of suction cups may be associated with the second frame. The second number of suction cups may be configured for attachment to the workpiece. The controller may be configured to control an application of a vacuum and a pressure by the first number of suction cups and the second number of suction cups during movement of the frame system. Moving the crawler assembly system from the first location to the second location may comprise applying the vacuum to the first number of suction cups and the pressure to the second number of suction cups, moving the second frame relative to the first frame while the first number of suction cups holds the first frame to the workpiece, applying the vacuum to the second number of suction cups after movement of the second frame, applying the pressure to the first number of suction cups after the vacuum is applied to the second number of suction cups, moving the first frame relative to the second frame while the second number of suction cups holds the second frame to the workpiece, and repeating the steps of applying the vacuum to the first number of suction cups and the pressure to the second number of suction cups, moving the second frame relative to the first frame while the first number of suction cups holds the first frame to the workpiece, applying the vacuum to the second number of suction cups after movement of the second frame, applying the pressure to the first number of suction cups after the vacuum is applied to the second number of suction cups, and moving the first frame relative to the second frame while the second number of suction cups holds the second frame to the workpiece until the second location is reached. The vacuum may be applied to a first portion of the first number of suction cups connected to a first portion of the number of legs and to a second portion of the first number of suction cups connected to a second portion of the number of legs. The pressure may be applied to the second number of suction cups. A first leg in the first portion of the number of legs may be rotated in a first direction around a first axis. A second leg in the second portion of the first number of legs may be rotated in a second direction about the first axis. Rotation of the first leg and the second leg may cause rotation of the frame system about a second axis that is substantially perpendicular to the surface of the workpiece. The number of operations may be performed at the location on the workpiece.

The features, functions, and advantages can be achieved independently in various embodiments of the present disclosure or may be combined in yet other embodiments in which further details may be seen with reference to the following description and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

The novel features believed characteristic of the advantageous embodiments are set forth in the appended claims. The advantageous embodiments, however, as well as a preferred mode of use, further objectives, and advantages thereof, will best be understood by reference to the following detailed description of an advantageous embodiment of the present disclosure when read in conjunction with the accompanying drawings, wherein:

FIG. **1** is an illustration of an aircraft manufacturing and service method in accordance with an advantageous embodiment;

FIG. **2** is an illustration of an aircraft in which an advantageous embodiment may be implemented;

FIG. **3** is an illustration of a manufacturing environment in accordance with an advantageous embodiment;

FIG. **4** is an illustration of a manufacturing environment in accordance with an advantageous embodiment;

FIG. **5** is an illustration of a crawler assembly system in accordance with an advantageous embodiment;

FIG. **6** is an illustration of a bottom view of a crawler assembly structure in accordance with an advantageous embodiment;

FIG. **7** is an illustration of a front view of a crawler assembly system in accordance with an advantageous embodiment;

FIG. **8** is an illustration of a cross-sectional side view of a portion of a crawler assembly system in accordance with an advantageous embodiment;

FIG. **9** is an illustration of a cross-sectional side view of a portion of a crawler assembly system in accordance with an advantageous embodiment;

FIG. **10** is an illustration of a crawler assembly system in accordance with an advantageous embodiment;

FIG. **11** is an illustration of a back view of a crawler assembly system placed on a workpiece in accordance with an advantageous embodiment;

FIG. **12** is an illustration of a crawler assembly system on a workpiece in accordance with an advantageous embodiment;

FIG. **13** is an illustration of a crawler assembly system on a workpiece in accordance with an advantageous embodiment;

FIG. **14** is an illustration of a crawler assembly system on a workpiece in accordance with an advantageous embodiment;

FIG. **15** is an illustration of a crawler assembly system on a workpiece in accordance with an advantageous embodiment;

FIG. **16** is an illustration of a crawler assembly system in accordance with an advantageous embodiment;

FIG. **17** is an illustration of a flowchart of a process for performing operations on a workpiece in accordance with an advantageous embodiment;

FIG. **18** is an illustration of a flowchart of a process for moving a crawler assembly system in accordance with an advantageous embodiment; and

FIG. **19** is an illustration of a flowchart of a process for adjusting the legs of a crawler assembly system in accordance with an advantageous embodiment.

DETAILED DESCRIPTION

Referring more particularly to the drawings, embodiments of the disclosure may be described in the context of aircraft manufacturing and service method **100** as shown in FIG. **1** and aircraft **200** as shown in FIG. **2**. Turning first to FIG. **1**, an illustration of an aircraft manufacturing and service method is depicted in accordance with an advantageous embodiment. During pre-production, aircraft manufacturing and service method **100** may include specification and design **102** of aircraft **200** in FIG. **2** and material procurement **104**.

During production, component and subassembly manufacturing **106** and system integration **108** of aircraft **200** in FIG. **2** takes place. Thereafter, aircraft **200** in FIG. **2** may go through certification and delivery **110** in order to be placed in service **112**. While in service **112** by a customer, aircraft **200**

in FIG. **2** may be scheduled for routine maintenance and service **114**, which may include modification, reconfiguration, refurbishment, and other maintenance or service.

Each of the processes of aircraft manufacturing and service method **100** may be performed or carried out by a system integrator, a third party, and/or an operator. In these examples, the operator may be a customer. For the purposes of this description, a system integrator may include, without limitation, any number of aircraft manufacturers and major-system subcontractors; a third party may include, without limitation, any number of venders, subcontractors, and suppliers; and an operator may be an airline, leasing company, military entity, service organization, and so on.

With reference now to FIG. **2**, an illustration of an aircraft is depicted in which an advantageous embodiment may be implemented. In this example, aircraft **200** may be produced by aircraft manufacturing and service method **100** in FIG. **1** and may include airframe **202** with a plurality of systems **204** and interior **206**. Examples of systems **204** may include one or more of propulsion system **208**, electrical system **210**, hydraulic system **212**, and environmental system **214**. Any number of other systems may be included. Although an aerospace example is shown, different advantageous embodiments may be applied to other industries, such as the automotive industry.

Apparatus and methods embodied herein may be employed during at least one of the stages of aircraft manufacturing and service method **100** in FIG. **1**. As used herein, the phrase "at least one of", when used with a list of items, means that different combinations of one or more of the listed items may be used and only one of each item in the list may be needed. For example, "at least one of item A, item B, and item C" may include, for example, without limitation, item A or item A and item B. This example also may include item A, item B, and item C or item B and item C.

In one illustrative example, components or subassemblies produced in component and subassembly manufacturing **106** in FIG. **1** may be fabricated or manufactured in a manner similar to components or subassemblies produced while aircraft **200** is in service **112** in FIG. **1**. As yet another example, a number of apparatus embodiments, method embodiments, or a combination thereof may be utilized during production stages, such as component and subassembly manufacturing **106** and system integration **108** in FIG. **1**. A number, when referring to items, means one or more items. For example, a number of apparatus embodiments may be one or more apparatus embodiments. A number of apparatus embodiments, method embodiments, or a combination thereof may be utilized while aircraft **200** is in service **112** and/or during maintenance and service **114** in FIG. **1**. The use of a number of the different advantageous embodiments may substantially expedite the assembly of and/or reduce the cost of aircraft **200**.

The different advantageous embodiments recognize and take into account a number of considerations. For example, without limitation, the different advantageous embodiments recognize and take into account that smaller robotic machines may be used to reach locations on or within a structure that larger robotic machines may not be able to reach. The different advantageous embodiments recognize and take into account that in locations in which larger robotic machines cannot be used, smaller robotic machines may be employed.

For example, without limitation, some robotic machines may move on the structure being assembled. These robotic machines may use a rail system for movement. A rail system may be attached to the structure.

As one illustrative example, without limitation, when skin panels are clamped to a frame for a fuselage, a rail system may be attached to the structure. The robotic machine may then move along the rails and perform operations to fasten the skin panels to the ribs. These robotic machines may drill holes and insert fasteners to attach skin panels to the ribs of the structure.

The different advantageous embodiments recognize that the use of robotic machines with rail systems may be cumbersome and more time consuming than desired. The rails may need to be repositioned from location to location. This repositioning may require removing the robotic machine, removing the rail, reinstalling the rail in the new location, and then placing the robotic machine back onto the rail.

The different advantageous embodiments also recognize and take into account that, in some cases, the robotic machines may have legs with suction cups. Those suction cups may engage and disengage themselves from the panels and move to different locations to perform operations. The movement of the legs along with the engagement and disengagement of the suction cups may occur in a manner that moves the machine.

The different advantageous embodiments recognize and take into account that these currently used machines may have a first frame and a second frame. The frames may move relative to each other. The legs on both frames may have suction cups that attach to the surface of the structure when a vacuum is applied.

When the robotic machine is ready to move to another location, the suction cups for the legs on one frame may be disengaged. Those legs may then be raised away from the surface of the structure. The first frame may then move relative to the second frame. Thereafter, the legs may be extended back onto the surface. A vacuum may be applied to the suction cups to reengage the suction cups to the surface. Thereafter, the suction cups or the legs on the second frame may be disengaged from the surface of the structure. Those legs may then be retracted. The second frame may move relative to the first frame. Thereafter, the legs may be re-extended and the suction cups may be engaged to the surface.

However, the different advantageous embodiments recognize and take into account that with these types of frames that move in parallel to each other, the systems may be more complex, heavier, and slower than desired. Further, the different advantageous embodiments also recognize that with the use of these types of systems, additional safety features may be needed. These safety features may include additional straps or lines to secure the robotic machine in case the vacuum generated by the suction cups does not provide the needed amount of vacuum to maintain attachment to the structure.

The different advantageous embodiments recognize and take into account that these types of systems may require more time to set up and operate than desired.

Thus, the different advantageous embodiments provide a method and apparatus for performing operations on a structure. In one advantageous embodiment, an apparatus may comprise a frame system, a first number of suction cups, a second number of suction cups, and a controller. The frame system may have a first frame and a second frame in which the frame system may be configured to hold an end effector that is configured to perform a number of operations. The first frame and the second frame may be configured for attachment to a workpiece. The controller may be configured to control attachment of the first frame and the second frame to the workpiece by applying a vacuum and a pressure during movement of the frame system.

With reference now to FIG. **3**, an illustration of a manufacturing environment is depicted in accordance with an advan-

tageous embodiment. In this illustrative example, manufacturing environment **300** may be an example of an environment that may be used to manufacture structures for aircraft **302**. Aircraft **302** may be an example of one implementation for aircraft **200** in FIG. **2**. Aircraft **302** may have fuselage **304** and nose **306**.

In this depicted example, crawler assembly system **308** may be used to manufacture structures for aircraft **302**. Crawler assembly system **308** may be an example of a robotic machine in this illustrative example. Crawler assembly system **308** may be used during at least one of component and subassembly manufacturing **106**, system integration **108**, maintenance and service **114**, and/or other suitable phases during aircraft manufacturing and service method **100** in FIG. **1**.

As depicted in this example, crawler assembly system **308** may be placed on surface **310** of fuselage **304**. As one illustrative example, crawler assembly system **308** may be used to install fasteners onto surface **310** of fuselage **304**. Additionally, crawler assembly system **308** may be used to perform a number of other operations to manufacture structures for aircraft **302**.

With reference now to FIG. **4**, an illustration of a manufacturing environment is depicted in accordance with an advantageous embodiment. Manufacturing environment **400** is an example of an environment that may be used to manufacture structures for aircraft **200** in FIG. **2**. Further, manufacturing environment **300** in FIG. **3** may be an example of one implementation for manufacturing environment **400** in FIG. **4**.

In these illustrative examples, manufacturing environment **400** may be used during at least one of component and subassembly manufacturing **106**, system integration **108**, maintenance and service **114**, and other suitable phases during aircraft manufacturing and service method **100** in FIG. **1**.

In these illustrative examples, crawler assembly system **402** may perform number of operations **404** on workpiece **406**. In these illustrative examples, workpiece **406** may be a structure or a portion of a structure for aircraft **200** in FIG. **2**. Of course, workpiece **406** may be for other types of objects other than aircraft **200** in FIG. **2**. For example, without limitation, workpiece **406** may be for an automobile, a truck, a building, a spacecraft, a missile, a ship, a submarine, a dam, a bridge, and/or some other suitable type of object.

In this illustrative example, crawler assembly system **402** may comprise frame system **408**, controller **410**, electromagnetic unit **412**, vacuum and pressure unit **414**, end effector **416**, sensor system **418**, and other suitable components. When electromagnetic unit **412** is present, crawler assembly system **402** may be referred to as an electromagnetic crawler assembly system.

Frame system **408** may comprise first frame **420**, second frame **422**, movement system **424**, first number of legs **426**, second number of legs **428**, first number of suction cups **430**, second number of suction cups **432**, and/or other suitable components. Frame system **408** may be configured to hold end effector **416**.

In these illustrative examples, first frame **420** and second frame **422** may move relative to each other. Movement system **424** may cause first frame **420** and second frame **422** to move relative to each other. In these examples, movement system **424** may comprise number of motors **434**.

First number of suction cups **430** may be associated with first frame **420** and may be configured for attachment to workpiece **406**. Second number of suction cups **432** may be associated with second frame **422**. Second number of suction cups **432** may be configured for attachment to workpiece **406**.

In these illustrative examples, a first component may be considered to be associated with a second component by being secured to the second component, bonded to the second component, fastened to the second component, and/or connected to the second component in some other suitable manner. The first component also may be connected to the second component through using a third component. The first component may also be considered to be associated with the second component by being formed as part of and/or an extension of the second component.

In these examples, first number of suction cups **430** may be associated with first frame **420** using first number of legs **426**. Second number of suction cups **432** may be associated with second frame **422** using second number of legs **428**.

In these illustrative examples, the attachment of first number of suction cups **430** and second number of suction cups **432** may be a removable attachment. The attachment may be caused by vacuum **436** applied by vacuum and pressure unit **414**. Vacuum **436** may be applied to first number of suction cups **430** through first number of legs **426** and to second number of suction cups **432** through second number of legs **428** in these examples. Vacuum **436** may cause first number of suction cups **430** and second number of suctions cups **432** to be attached to workpiece **406**.

In these illustrative examples, vacuum **436** may be applied through at least a portion of first number of suction cups **430** and second number of suction cups **432** to attach portion **438** of first number of suction cups **430** and/or portion **439** of second number of suction cups **432** to surface **440** of workpiece **406**. In these examples, first number of suction cups **430** and second number of suction cups **432** may have a number of different shapes and/or sizes.

In these illustrative examples, first number of legs **426** and second number of legs **428** may be moveable relative to surface **440** of workpiece **406**. First number of legs **426** and second number of legs **428** may be moveable to conform to surface **440**. For example, without limitation, surface **440** may be curved about one or more different axes (not shown). First number of legs **426** and/or second number of legs **428** may be moved relative to surface **440** to allow first number of suction cups **430** and/or second number of suction cups **432** to contact surface **440**.

In this manner, vacuum **436** may be applied to attach first number of suction cups **430** and/or second number of suction cups **432** to surface **440** of workpiece **406**. The positioning or movement of first number of legs **426** and/or second number of legs **428** may be performed using movement system **424**.

In these illustrative examples, movement of crawler assembly system **402** may be accomplished in any number of different ways. In one illustrative example, first number of suction cups **430** and second number of suction cups **432** may be attached to surface **440** of workpiece **406** during the performance of number of operations **404**.

In these illustrative examples, end effector **416** may perform number of operations **404** under the control of controller **410**. End effector **416** may comprise at least one of drill unit **441**, fastener system **443**, sealant unit **445**, vision system **447**, and/or other suitable devices. End effector **416** may be a device that may be moved by crawler assembly system **402** to different locations on workpiece **406** to perform number of operations **404**.

In these depicted examples, number of operations **404** may be performed at location **444** within area **442** of workpiece **406**. Area **442** may be an area within which end effector **416** may be moved by crawler assembly system **402** without mov-

ing frame system **408**. After number of operations **404** have been performed, crawler assembly system **402** may be moved to location **448**.

In these illustrative examples, end effector **416** may be stabilized using electromagnetic unit **412**. Electromagnetic unit **412** may be associated with first frame **420**. Electromagnetic unit **412** may engage magnetic material **446** on workpiece **406** to provide better attachment of crawler assembly system **402** to workpiece **406** during performance of number of operations **404**. This provides attachment in addition to applying vacuum **436** to first number of suction cups **430** and second number of suction cups **432**.

When moving from location **444** to location **448**, vacuum **436** may be applied to first number of suction cups **430** and pressure **450** may be applied to second number of suction cups **432**. Pressure **450** may provide force **452** to lift second frame **422** away from surface **440** of workpiece **406**.

In these illustrative examples, first number of suction cups **430** and second number of suction cups **432** may also be configured to apply vacuum **436** and/or pressure **450**. Suction cups of various geometries may be used to implement first number of suction cups **430** and second number of suction cups **432**. Examples of suction cups that may be used include, for example, without limitation, suction cups available from Piab USA, Inc.

Second frame **422** may be moved relative to first frame **420** by movement system **424** while pressure **450** is applied to second number of suction cups **432** and vacuum **436** is applied to first number of suction cups **430**. After movement of second frame **422** has completed, vacuum **436** may be applied to second number of suction cups **432**.

Additionally, pressure **450** may be applied to first number of suction cups **430** while vacuum **436** is applied to second number of suction cups **432**. Then, first frame **420** may be moved relative to second frame **422** while vacuum **436** is applied to second number of suction cups **432** and pressure **450** is applied to first number of suction cups **430**. This sequence of steps may be performed to move workpiece **406** from location **444** to location **448**.

Additionally, in some advantageous embodiments, first frame **420** and second frame **422** may move relative to each other to move frame system **408** from location **444** to location **448**, while end effector **416** performs number of operations **404**. In this manner, pauses in the performance of number of operations **404** for movement of crawler assembly system **402** may be reduced and/or avoided.

Further, electromagnetic unit **412** may provide force **454** to hold first frame **420** on workpiece **406**, while second frame **422** moves relative to first frame **420**. Additionally, electromagnetic unit **412** may provide an additional mechanism to hold crawler assembly system **402** on workpiece **406** in case first number of suction cups **430** and second number of suction cups **432** are unable to hold frame system **408** on workpiece **406**.

In these illustrative examples, controller **410** may comprise a computer, a processor unit, an application specific integrated circuit, or some other suitable device that controls the operation of crawler assembly system **402**. Controller **410** may be configured to control attachment of first frame **420** and second frame **422** to workpiece **406** by applying vacuum **436** and pressure **450** during movement of frame system **408**. Controller **410** may store locations and/or operations to be performed on workpiece **406** in the form of program code **456**. Program code **456** may be run to perform number of operations **404** on workpiece **406**.

Sensor system **418**, in these illustrative examples, may be used to identify the location of crawler assembly system **402** on workpiece **406**. Further, sensor system **418** may be used to position end effector **416** relative to workpiece **406**. Sensor system **418** also may be used to perform inspections on number of operations **404**. In these illustrative examples, sensor system **418** may comprise, for example, without limitation, infrared sensors, cameras, ultrasonic sensors, and/or other suitable types of sensors.

The illustration of manufacturing environment **400** is not meant to imply physical architectural limitations to the manner in which different advantageous embodiments may be implemented. Other components in addition to and/or in place of the ones illustrated may be used. Some components may be unnecessary in some advantageous embodiments. Also, the blocks are presented to illustrate some functional components. One or more of these blocks may be combined and/or divided into different blocks when implemented in different advantageous embodiments.

For example, in some advantageous embodiments, crawler assembly systems in addition to crawler assembly system **402** may be present to perform operations on workpiece **406**. In still other advantageous embodiments, crawler assembly system **402** may comprise a number of additional end effectors in addition to end effector **416**. Also, additional electromagnetic units in addition to electromagnetic unit **412** may be present.

In these illustrative examples, first leg **458** and second leg **462** in first number of legs **426** may be configured to rotate about axis **460**. The rotation of first leg **458** and/or second leg **462** about axis **460** may cause electromagnetic unit **412** to rotate about axis **460**. In this manner, the positioning of electromagnetic unit **412** may be performed for different types of surfaces on workpiece **406**.

With reference now to FIG. **5**, an illustration of a crawler assembly system is depicted in accordance with an advantageous embodiment. In this illustrative example, crawler assembly system **500** may be an example of one implementation for crawler assembly system **308** in FIG. **3** and/or crawler assembly system **402** in FIG. **4**.

Crawler assembly system **500** may include frame system **502**, electromagnetic unit **504**, vacuum and pressure unit **506**, end effector **508**, sensor system **510**, and controller **512**. In this illustrative example, frame system **502** may comprise first frame **514**, second frame **516**, movement system **518**, first number of legs **520**, second number of legs **522**, first number of suction cups **524**, and second number of suction cups **526**.

In this depicted example, second frame **516** may include portion **511** and portion **513**. Portion **511** and portion **513** may be attached to each other to form second frame **516**. Further, first frame **514** may be associated with portion **513** of second frame **516**.

First frame **514** and second frame **516** may move relative to each other using movement system **518**. Movement system **518** may include motor **528** in this illustrative example. Additionally, movement system **518** may include motors **552**, **553**, **554**, **555**, **556**, **557**, **558**, **559**, **560**, and **561**. Movement system **518** may be used to move at least a portion of first number of legs **520** relative to at least a first portion of second number of legs **522**.

In this depicted example, first number of legs **520** and first number of suction cups **524** may be associated with first frame **514**. First number of legs **520** may include leg **530** and leg **531**. First number of suction cups **524** may include suction cup **532** and suction cup **533** attached to leg **530** and leg **531**, respectively. First number of suction cups **524** may be configured to be attached to a surface of a workpiece (not shown), such as workpiece **406** in FIG. **4**.

Second number of legs **522** and second number of suction cups **526** may be associated with second frame **516**. Second number of legs **522** may include legs **534**, **535**, **536**, **537**, **538**, **539**, **540**, and **541**. Second number of suction cups **526** may include suction cups **542**, **543**, **544**, **545**, **546**, **547**, and **548** attached to legs **534**, **535**, **536**, **537**, **538**, **539**, and **541**, respectively, and another suction cup (not shown) attached to leg **540**. Second number of suction cups **526** also may be configured to be attached to the surface of the workpiece.

In this illustrative example, first number of legs **520** and second number of legs **522** may be moveable. Movement of first number of legs **520** and/or second number of legs **522** may be provided by movement system **518**.

For example, without limitation, motor **552** and motor **553** may move leg **530** and leg **531**, respectively, vertically in the direction of arrow **549**. Further, motors **554**, **555**, **556**, **557**, **558**, **559**, **560**, and **561** may be associated with legs **534**, **535**, **536**, **537**, **538**, **539**, **540**, and **541**, respectively. Each of these motors may be configured to move a corresponding leg vertically in the direction of arrow **549**. Legs within first number of legs **520** and/or second number of legs **522** may be moved to different positions by movement system **518**.

With this type of movement for first number of legs **520** and second number of legs **522**, first number of legs **520** and second number of legs **522** may be capable of substantially conforming to the surface of the workpiece when the surface is a curved surface. For example, legs within first number of legs **520** and/or second number of legs **522** may be moved such that first number of suction cups **524** and second number of suction cups **526** may all contact the curved surface of the workpiece.

The attachment of first number of suction cups **524** and second number of suction cups **526** to the workpiece may be performed using vacuum and pressure unit **506**. Vacuum and pressure unit **506** may include lines that connect vacuum and pressure unit **506** to first number of legs **520** and second number of legs **522**.

For example, without limitation, vacuum and pressure unit **506** may include lines **562**, **563**, **564**, **565**, **566**, **567**, **568**, and **569** that connect to legs **534**, **535**, **536**, **537**, **538**, **539**, **540**, and **541**, respectively. Further, vacuum and pressure unit **506** may include line **570** and line **571** that connect to leg **530** and leg **531**, respectively. Vacuum and pressure unit **506** may apply a vacuum and/or pressure to these legs through these lines.

Vacuum and pressure unit **506** may generate a vacuum such that at least a portion of first number of suction cups **524** and/or second number of suction cups **526** may attach to a surface of the workpiece. In particular, vacuum and pressure unit **506** may generate a vacuum through at least a portion of second number of legs **522** and/or first number of legs **520** such that at least a portion of first number of suction cups **524** and/or second number of suction cups **526** may attach to a surface of the workpiece. In other words, vacuum and pressure unit **506** may evacuate the air within at least a portion of first number of suction cups **524** and/or second number of suction cups **526** to generate the vacuum that allows attachment to the surface of the workpiece.

In this illustrative example, first frame **514** may move relative to second frame **516** in the direction of arrow **549** and the direction of arrow **525** using vacuum and pressure unit **506** and movement system **518**. For example, without limitation, vacuum and pressure unit **506** may apply a vacuum to first number of suction cups **524**. The vacuum may cause first number of suction cups **524** to attach to the surface of the workpiece.

Vacuum and pressure unit **506** may also apply pressure to second number of suction cups **526**. In other words, vacuum and pressure unit **506** may pressurize second number of suction cups **526** instead of applying a vacuum to second number of suction cups **526**. This pressurization may provide a force to lift second number of suctions cups **526** off the surface of the workpiece. Further, the pressurization of second number of suction cups **526** may be provided by a cushion of air in this illustrative example. In this manner, second frame **516** may be lifted off of the surface of the workpiece by the pressure applied by vacuum and pressure unit **506**.

With second frame **516** lifted off the surface of the workpiece, motor **528** may be operated to move second frame **516** relative to first frame **514**. Second frame **516** may be moved in the direction of arrow **525** while first frame **514** remains attached to the surface of the workpiece by first number of suction cups **524**.

When second frame **516** has been moved to the desired location, vacuum and pressure unit **506** may apply a vacuum to second number of suction cups **526** to attach second number of suction cups **526** to the surface of the workpiece. In these illustrative examples, crawler assembly system **500** may be moved over the surface of the workpiece by moving either first frame **514** or second frame **516** first.

In these depicted examples, each suction cup in first number of suction cups **524** and second number of suction cups **526** may have a flexibility that may allow each suction cup to attach to a curved surface. Further, this flexibility may allow at least a portion of first number of suction cups **524** and/or second number of suction cups **526** to attach to a surface at an angle relative to a surface to which another portion of first number of suction cups **524** and/or second number of suction cups **526** is attached. As one illustrative example, one portion of second number of suction cups **526** may be attached to a portion of a surface at a first angle and another portion of second number of suction cups **526** may be attached to another portion of the surface at a second angle.

Additionally, crawler assembly system **500** may also have motor **550** and motor **551** associated with first frame **514**. Motor **550** and motor **551** may be electric motors, air motors, air cylinders, and/or some other suitable type of motor. Motor **550** and motor **551** may be used to rotate at least one of leg **530** and leg **531**. For example, without limitation, leg **530** may be rotated in a first direction about axis **590**, and leg **531** may be rotated in a second direction about axis **590**. Rotation of leg **530** and leg **531**, while a vacuum is applied to suction cup **532** and suction cup **533**, may cause rotation of frame system **502** about axis **592**. Rotation of frame system **502** about axis **592** may cause crawler assembly system **500** to turn on the surface of a workpiece.

Additionally, motor **550** and motor **551** may be used to rotate leg **530** and leg **531** such that suction cup **532** and suction cup **533** may contact a curved surface for the workpiece.

In this illustrative example, electromagnetic unit **504** may provide additional attachment of crawler assembly system **500** to the workpiece. For example, without limitation, electromagnetic unit **504** may provide additional attachment of crawler assembly system **500** to the workpiece if any of the suctions cups in first number of suction cups **524** or second number of suction cups **526** do not attach to the workpiece as desired.

Additionally, end effector **508** may be used to perform a number of operations on the workpiece. In this illustrative example, end effector **508** may include drill unit **580** and fastener system **581**. Drill unit **580** may be used to perform drilling operations, and fastener system **581** may be used to perform fastening operations. These operations may be performed while first frame **514** is attached to the workpiece.

Second frame **516** may be attached to the workpiece or may be moving towards a desired location while the operations are performed by end effector **508**.

In this illustrative example, sensor system **510** may be used to generate information about the surface of the workpiece on which the operations are to be performed. For example, without limitation, sensor system **510** may include camera **582** in this depicted example. Camera **582** may be used to generate image information used to identify the location at which the operations are to be performed. Further, the image information may also be used for positioning drill unit **580** and/or fastener system **581** for performing the operations.

As depicted in this illustrative example, controller **512** may be associated with first frame **514**. Controller **512** may take the form of computer system **584** in this depicted example. Computer system **584** may be used to control crawler assembly system **500**. For example, without limitation, computer system **584** may be used to control the movement of crawler assembly system **500** by movement system **518**, the positioning of end effector **508**, the types of operations performed by end effector **508**, and/or other suitable operations.

In these illustrative examples, controller **512** may be operated manually and/or automatically. For example, in some cases, controller **512** may run program code to control crawler assembly system **500**. In other examples, controller **512** may be operated by a human operator.

With reference now to FIG. **6**, an illustration of a bottom view of a crawler assembly structure is depicted in accordance with an advantageous embodiment. In this illustrative example, suction cup **600** in second number of suction cups **526** for crawler assembly system **500** in FIG. **5** may be seen. Suction cup **600** may be associated with leg **540** in second number of legs **522** in FIG. **5**.

With reference now to FIG. **7**, an illustration of a front view of a crawler assembly system is depicted in accordance with an advantageous embodiment. In this illustrative example, crawler assembly system **500** may be seen from the front of first frame **514**. As depicted, crawler assembly system **500** may be placed on workpiece **700**. In particular, suction cups **546**, **547**, **600**, and **548** may be seen attached to surface **702** of workpiece **700**.

With reference now to FIG. **8**, an illustration of a cross-sectional side view of a portion of a crawler assembly system is depicted in accordance with an advantageous embodiment. As depicted in this example, crawler assembly system **500** may use motor **550** to rotate leg **530** about axis **590** substantially perpendicular to axis **592**. Leg **530** may be rotated about axis **590** such that center line **802** for leg **530** may be rotated about plus or minus five degrees away from axis **592** in the direction of arrow **800**.

With reference now to FIG. **9**, an illustration of a cross-sectional side view of a portion of a crawler assembly system is depicted in accordance with an advantageous embodiment. In this illustrative example, center line **802** for leg **530** has been rotated to position **900**. As depicted, position **900** may be about plus five degrees away from axis **592**. The rotation of leg **530** may be caused by the operation of motor **550** in this illustrative example.

Additionally, leg **531** in FIG. **5** may also be rotated to a position away from axis **592** in a direction opposite to the rotation of leg **530** in this illustrative example. Rotation of these two legs in opposite directions may cause frame system **502** to rotate about axis **592**. In this manner, crawler assembly system **500** may be turned using motor **550** and motor **551** in FIG. **5** to rotate leg **530** and leg **531**, respectively.

With reference now to FIG. **10**, an illustration of a crawler assembly system is depicted in accordance with an advantageous embodiment. In this illustrative example, crawler assembly system **500** may have a different configuration as compared to the configuration for crawler assembly system **500** in FIG. **5**.

As depicted in this example, portion **511** of second frame **516** may be removed. Only portion **513** of second frame **516** may be present for crawler assembly system **500**. Removal of portion **511** may reduce the size and/or weight of crawler assembly system **500**. This reduction in size and/or weight may allow crawler assembly system **500** to move to a greater number of locations and be in a greater number of positions as compared to when portion **511** is present for crawler assembly system **500**.

With reference now to FIG. **11**, an illustration of a back view of a crawler assembly system placed on a workpiece is depicted in accordance with an advantageous embodiment. In this illustrative example, a back view of crawler assembly system **500** may be illustrated taken along lines **11-11** in FIG. **10**. As depicted, crawler assembly system **500** may be shown from the view of controller **512**.

In this illustrative example, crawler assembly system **500** may be placed on workpiece **1100**. Workpiece **1100** may have curved surface **1102** in this illustrative example. Legs **538**, **539**, **540**, and **541** may be moved such that suction cup **546**, **547**, **600**, and **548** are in contact with curved surface **1102**.

In this illustrative example, suction cup **532** and suction cup **533** may not be in contact with curved surface **1102** such that first frame **514** may be moved along axis **1104**. For example, without limitation, vacuum and pressure unit **506** may apply pressure to suction cup **532** and suction cup **533**. In other words, the vacuum applied to suction cup **532** and suction cup **533** may be removed by pressurizing suction cup **532** and suction cup **533**.

This pressurization of these suction cups may provide the force needed to lift suction cup **532** and suction cup **533** off of curved surface **1102**. In particular, this force may be provided by, for example, without limitation, cushion of air **1106** under suction cup **532** and cushion of air **1108** under suction cup **533**. When suction cup **532** and suction cup **533** are lifted off of curved surface **1102**, first frame **514** may be moved along axis **1104** to a desired location.

Further, leg **530** in FIG. **9** and leg **531** in FIG. **7** may be moved such that suction cup **532** and suction cup **533** may not come in contact with curved surface **1102** while first frame **514** is moved. In some illustrative examples, leg **530** and leg **531** may not need to be moved, because cushion of air **1106** and cushion of air **1108** may provide force sufficient to lift suction cup **532** and suction cup **533**, respectively, off of curved surface **1102** as first frame **514** is moved along axis **1104**.

With reference now to FIGS. **12-15**, illustrations of a crawler assembly system on a workpiece are depicted in accordance with an advantageous embodiment. In these illustrative examples, crawler assembly system **500** in FIGS. **12-15** has the configuration presented in FIG. **10**.

Turning now to FIG. **12**, crawler assembly system **500** may be placed on workpiece **1200**. Suction cups **532**, **533**, **546**, **547**, **600**, and **548** may be attached to surface **1202** of workpiece **1200**. Suction cups **532**, **533**, **546**, **547**, **600**, and **548** may be attached to surface **1202** using a vacuum provided by vacuum and pressure unit **506**.

As depicted in this example, electromagnetic unit **504** may attach to magnetic material **1204** positioned under workpiece **1200** to provide additional attachment of crawler assembly system **500** to workpiece **1200** in addition to the attachment provided by suction cups **532**, **533**, **546**, **547**, **600**, and **548**.

In this illustrative example, first frame **514** may be in position **1206** on workpiece **1200**. First frame **514** may be in position **1206** such that fastener unit **581** may be placed over location **1208** on workpiece **1200**. Fastener unit **581** for end effector **508** may be used to perform fastening operations at location **1208** on workpiece **1200**.

In FIG. **13**, when fastening operations have been completed, controller **512** may release the attachment of electromagnetic unit **504** from surface **1202** of workpiece **1200**. Further, vacuum and pressure unit **506** may apply pressure to suction cup **532** and suction cup **533** to lift suction cup **532** and suction cup **533** off of surface **1202**.

Turning now to FIG. **14**, with suction cup **532** and suction cup **533** no longer in contact with surface **1202**, first frame **514** may be moved from position **1204** in FIGS. **12** and **13** in the direction of arrow **1400** to position **1402**. Second frame **516** may not move while first frame **514** is moved.

In FIG. **15**, controller **512** may control electromagnetic unit **504** such that electromagnetic unit **504** attaches to surface **1202**. Further, vacuum and pressure unit **506** may apply a vacuum to suction cup **532** and suction cup **533** such that suction cup **532** and suction cup **533** attach to surface **1202**. With first frame **514** at position **1402** and suction cup **532** and suction cup **533** attached to surface **1202**, fastener system **581** may be used to perform fastening operations at location **1500** on workpiece **1200**.

With reference now to FIG. **16**, an illustration of a crawler assembly system is depicted in accordance with an advantageous embodiment. In this illustrative example, crawler assembly system **1600** may be an example of one implementation of crawler assembly system **402** in FIG. **4** and/or crawler assembly system **308** in FIG. **3**.

As depicted in this example, crawler assembly system **1600** may include frame system **1602**, electromagnetic unit **1604**, vacuum and pressure unit **1606**, end effector **1608**, and sensor system **1610**. Frame system **1602** may comprise first frame **1612**, second frame **1614**, movement system **1616**, first number of legs **1618**, second number of legs **1620**, first number of suction cups **1622**, and second number of suction cups **1624**.

In this illustrative example, first frame **1612** may be positioned within interior **1615** of second frame **1614**. This configuration for crawler assembly system **1600** may be different than the configuration for crawler assembly system **500** in FIG. **5** and in FIG. **9**.

First number of legs **1618** may be associated with first frame **1612** and may include leg **1640** and leg **1641**. Second number of legs **1620** may be associated with second frame **1614** and may include legs **1626**, **1627**, **1628**, **1629**, **1630**, **1631**, **1632**, **1633**, **1634**, **1635**, **1636**, **1637**, **1638**, and **1639**.

First number of suction cups **1622** may include suction cup **1643** attached to leg **1641** and another suction cup (not shown) attached to leg **1640**. Second number of suction cups **1624** may include suction cups **1644**, **1645**, **1646**, **1647**, **1648**, **1649**, **1650**, **1651**, **1652**, **1653**, **1654**, **1655**, **1656**, and **1657** attached to legs **1626**, **1627**, **1628**, **1629**, **1630**, **1631**, **1632**, **1633**, **1634**, **1635**, **1636**, **1637**, **1638**, and **1639**, respectively.

In these illustrative examples, movement system **1616** may be configured to move first frame **1612** relative to second frame **1614**. Movement system **1616** may be configured to move first frame **1612** and/or second frame **1614** along axis **1617**.

Further, movement system **1616** may be configured to move first number of legs **1618** and/or second number of legs **1620** vertically such that first number of suction cups **1622** and/or second number of suction cups **1624** may all contact the surface of a workpiece (not shown).

Movement system **1616** may include motors **1658**, **1659**, **1660**, **1661**, **1662**, **1663**, **1664**, **1665**, **1666**, **1667**, **1668**, **1669**, **1670**, and **1671** associated with legs **1626**, **1627**, **1628**, **1629**, **1630**, **1631**, **1632**, **1633**, **1634**, **1635**, **1636**, **1637**, **1638**, and **1639**, respectively. Further, movement system **1616** may include motor **1672** associated with leg **1640**, motor **1673** associated with leg **1641**, and/or other suitable motors not shown in this view.

In this illustrative example, motor **1676** and motor **1677** may be associated with first frame **1612**. Motor **1676** may tilt leg **1640** and/or motor **1677** may tilt leg **1641** relative to the surface of the workpiece such that first number of suction cups **1622** may conform to the surface of the workpiece.

Electromagnetic unit **1604** may provide additional attachment for crawler assembly system **1600** to a workpiece. Additionally, end effector **1608** may include fastener system **1678** and drill unit **1680**. Fastener system **1678** and drill unit **1680** may be associated with first frame **1612**. Fastener system **1678** may be used to perform fastening operations on the workpiece. Drill unit **1680** may be used to perform drilling operations on the workpiece.

Sensor system **1610** may be used to identify the location on the workpiece at which to perform operations. Further, sensor system **1610** may be used to position end effector **1608** to perform the operations and/or inspect the operations being performed.

With reference now to FIG. **17**, an illustration of a flowchart of a process for performing operations on a workpiece is depicted in accordance with an advantageous embodiment. The process illustrated in FIG. **17** may be implemented using crawler assembly system **402** in FIG. **4**.

The process may begin by selecting a location to which to move crawler assembly system **402** (operation **1700**). Crawler assembly system **402** may comprise frame system **408** having first frame **420**, second frame **422**, first number of suction cups **430**, second number of suction cups **432**, and controller **410**. Frame system **408** may be configured to hold end effector **416**. End effector **416** may be configured to perform number of operations **404**.

The process may then move crawler assembly system **402** to the selected location (operation **1702**). Next, the process may perform number of operations **404** at the selected location on workpiece **406** (operation **1704**).

Thereafter, the process may determine whether another location is present for processing (operation **1706**). If another location is present for processing, the process returns to operation **1700**. Otherwise, the process may terminate.

With reference now to FIG. **18**, an illustration of a flowchart of a process for moving a crawler assembly system is depicted in accordance with an advantageous embodiment. The process illustrated in FIG. **18** may be implemented using crawler assembly system **402** in FIG. **4**. This process may be a more-detailed process for operation **1702** in FIG. **17**.

The process may begin by applying pressure **450** to first number of suction cups **430** (operation **1800**). Pressure **450** may provide force **452** that may lift first number of suction cups **430** off of surface **440** of workpiece **406**. In this illustrative example, vacuum **436** may be applied to second number of suction cups **432** such that second number of suction cups **432** may be attached to surface **440** of workpiece **406**.

The process may then disengage electromagnetic unit **412** from workpiece **406** (operation **1802**). Next, the process may move first frame **420** to a selected location (operation **1804**). Second frame **422** may not move when first frame **420** is moved to the selected location.

Thereafter, the process may apply vacuum **436** to first number of suction cups **430** (operation **1806**). Next, the pro-

cess may engage electromagnetic unit **412** such that electromagnetic unit **412** attaches to workpiece **406** (operation **1808**).

The process may then apply pressure to second number of suction cups **432** to remove vacuum **436** applied to second number of suction cups **432** (operation **1810**). Next, the process may move second frame **422** (operation **1812**). Thereafter, the process may determine whether movement of crawler assembly system **402** to the selected location has been completed (operation **1814**). If movement of crawler assembly system **402** to the selected location has not been completed, the process may return to operation **1800** as described above. Otherwise, the process may terminate.

With reference now to FIG. **19**, an illustration of a flowchart of a process for adjusting the legs of a crawler assembly system is depicted in accordance with an advantageous embodiment. The process illustrated in FIG. **19** may be implemented using crawler assembly system **402** in FIG. **4**.

The process may begin by identifying the contour of surface **440** of workpiece **406** (operation **1900**). For example, without limitation, in operation **1900**, the contour may be identified as curved, jagged, straight, and/or having some other type of contour. Additionally, the contour may be identified as a complex contour in which the contour is curved in at least two directions.

Thereafter, the process may select a number of legs within first number of legs **426** and/or second number of legs **428** (operation **1902**). The process may then adjust the selected number of legs (operation **1904**), with the process terminating thereafter.

In operation **1904**, the selected number of legs may be adjusted by moving at least a portion of the selected number of legs vertically to adjust for the contour of surface **440**. Further, the selected number of legs may be adjusted by tilting at least a portion of the selected number of legs in second number of legs **428** relative to surface **440**. Tilting of this portion of the selected number of legs may allow electromagnetic unit **412** to be tilted such that electromagnetic unit **412** may attach to surface **440**.

The flowcharts and block diagrams in the different depicted embodiments illustrate the architecture, functionality, and operation of some possible implementations of apparatus and methods in different advantageous embodiments. In this regard, each block in the flowcharts or block diagrams may represent a module, segment, function, and/or a portion of an operation or step.

In some alternative implementations, the function or functions noted in the block may occur out of the order noted in the figures. For example, in some cases, two blocks shown in succession may be executed substantially concurrently, or the blocks may sometimes be executed in the reverse order, depending upon the functionality involved. Also, other blocks may be added in addition to the illustrated blocks in a flowchart or block diagram.

For example, in some advantageous embodiments, operation **1706** may be performed while operation **1704** is being performed. In other words, the determination as to whether to move crawler assembly system **402** to another location may be made while operation **1704** is being performed. Further, if another location is present for processing, operations **1700** and **1702** may also be performed while operation **1704** is being performed.

Thus, the different advantageous embodiments provide a method and apparatus for performing operations on a workpiece. In one advantageous embodiment, an apparatus may comprise a frame system, a first number of suction cups, a second number of suction cups, and a controller. The frame system may have a first frame and a second frame in which the frame system may be configured to hold an end effector. The end effector may be configured to perform a number of operations. The first number of suction cups may be associated with the first frame in which the first number of suction cups is configured for attachment to a workpiece.

The second number of suction cups may be associated with the second frame in which the second number of suction cups may be configured for attachment to a workpiece. The controller may be configured to control an application of a vacuum and a pressure by the first number of suction cups and the second number of suction cups during movement of the first frame and the second frame relative to each other on the workpiece.

The description of the different advantageous embodiments has been presented for purposes of illustration and description and is not intended to be exhaustive or limited to the embodiments in the form disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art. Further, different advantageous embodiments may provide different advantages as compared to other advantageous embodiments. The embodiment or embodiments selected are chosen and described in order to best explain the principles of the embodiments, the practical application, and to enable others of ordinary skill in the art to understand the disclosure for various embodiments with various modifications as are suited to the particular use contemplated.

What is claimed is:

1. A method for performing operations on a workpiece, the method comprising:

holding a first frame in a frame system on the workpiece by applying a vacuum to the first frame, wherein the frame system is part of a crawler assembly system, the crawler assembly system comprises an end effector associated with the frame system and configured to perform an operation on the workpiece, the workpiece is a portion of a structure of a vehicle or building, and wherein the workpiece includes magnetic material;

detaching a second frame in the frame system from the workpiece by applying a pressure to the second frame;

moving the second frame to a location on the workpiece;

attaching the second frame to the workpiece by applying the vacuum to the second frame;

attracting the magnetic material of the workpiece with an electromagnetic unit associated with the first frame to aid in the attaching of the first frame to the workpiece, wherein a channel extending through the electromagnetic unit receives the end effector and allows the end effector to reach a surface of the workpiece when the electromagnetic unit attracts the magnetic material of the workpiece; and

performing the operation on the workpiece.

2. The method of claim **1**, wherein the crawler system further comprises a first number of suction cups associated with the first frame in which the first number of suction cups is configured for attachment to the workpiece; a second number of suction cups associated with the second frame in which the second number of suction cups is configured for the attachment to the workpiece; and a controller configured to control an application of the vacuum and the pressure by the first number of suction cups and the second number of suction cups during movement of the frame system.

3. The method of claim **2**, wherein a number of legs connect the first number of suction cups to the first frame and further comprising:

applying the vacuum to a first portion of the first number of suction cups connected to a first portion of the number of

legs and to a second portion of the first number of suction cups connected to a second portion of the number of legs;

applying the pressure to the second number of suction cups; and

moving the first portion of the number of legs in a first direction and the second portion of the number of legs in a second direction such that the frame system turns on the surface of the workpiece.

4. The method of claim **3**, wherein the step of moving the first portion of the number of legs in the first direction and the second portion of the number of legs in the second direction such that the frame system turns on the surface of the workpiece comprises:

rotating a first leg in the first portion of the number of legs in the first direction about a first axis; and

rotating a second leg in the second portion of the number of legs in the second direction about the first axis, wherein rotation of the first leg and the second leg about the first axis causes rotation of the frame system about a second axis that is substantially perpendicular to the surface of the workpiece.

5. The method of claim **2**, wherein the step of holding the first frame in the frame system on the workpiece by applying the vacuum to the first frame comprises:

applying the vacuum to the first number of suction cups to hold the first frame in the frame system on the workpiece;

wherein the step of detaching the second frame in the frame system from the workpiece by applying the pressure to the second frame comprises:

applying the pressure to the second number of suction cups to detach the second frame in the frame system from the workpiece;

wherein the step of attaching the second frame to the workpiece by applying the vacuum to the second frame comprises:

applying the vacuum to the second number of suction cups after movement of the second frame to attach the second frame to the workpiece;

and further comprising:

applying the pressure to the first number of suction cups after the vacuum is applied to the second number of suction cups; and

moving the first frame relative to the second frame while the second number of suction cups holds the second frame on the workpiece.

6. The method of claim **2**, wherein the location is a first location and further comprising:

moving the crawler assembly system towards a second location while the end effector performs a number of operations on the workpiece.

7. The method of claim **2** further comprising:

applying both the vacuum and the pressure to the first number of suction cups and the second number of suction cups through a vacuum and pressure unit connected to the first number of suction cups and the second number of suction cups.

8. The method of claim **2**, wherein applying the pressure by the first number of suction cups and the second number of suction cups provides a force to lift.

9. The method of claim **1**, further comprising:

moving the first frame and the second frame relative to each other with a movement system.

10. The method of claim **1**, wherein the end effector comprises at least one of a drill unit, a fastener system, a sealant unit, and a vision system.

11. The method of claim **1**, further comprising determining, with a sensor system in communication with a controller, a location of the crawler assembly where the end effector performs at least one operation in the number of operations on the workpiece.

12. The method of claim **1**, wherein the workpiece is a surface of a fuselage of the vehicle.

13. The method of claim **12**, wherein the vehicle is one of an aircraft, an automobile, a truck, a spacecraft, a missile, a ship, or a submarine.

14. The method of claim **12**, wherein the vehicle is one of an aircraft, a spacecraft, or a missile.

15. A method for performing operations on a workpiece, the method comprising:

moving a crawler assembly system from a first location on the workpiece to a second location on the workpiece, wherein the workpiece is a portion of a structure of a vehicle or building, the workpiece includes magnetic material, and wherein the crawler assembly system comprises a frame system having a first frame and a second frame in which the frame system is configured to hold an end effector that is configured to perform a number of operations; a first number of suction cups associated with the first frame by a number of legs in which the first number of suction cups is configured for attachment to the workpiece; a second number of suction cups associated with the second frame in which the second number of suction cups is configured for attachment to the workpiece; and a controller configured to control an application of a vacuum and a pressure by the first number of suction cups and the second number of suction cups during movement of the frame system, in which the step of moving the crawler assembly system from the first location on the workpiece to the second location on the workpiece comprises:

applying the vacuum to the first number of suction cups and the pressure to the second number of suction cups;

moving the second frame relative to the first frame while the first number of suction cups holds the first frame to the workpiece;

applying the vacuum to the second number of suction cups after movement of the second frame;

applying the pressure to the first number of suction cups after the vacuum is applied to the second number of suction cups;

moving the first frame relative to the second frame while the second number of suction cups holds the second frame to the workpiece;

repeating the steps of applying the vacuum to the first number of suction cups and the pressure to the second number of suction cups; moving the second frame relative to the first frame while the first number of suction cups holds the first frame to the workpiece; applying the vacuum to the second number of suction cups after the movement of the second frame; applying the pressure to the first number of suction cups after the vacuum is applied to the second number of suction cups; and moving the first frame relative to the second frame while the second number of suction cups holds the second frame to the workpiece until the second location on the workpiece is reached;

applying the vacuum to a first portion of the first number of suction cups connected to a first portion of the number of legs and to a second portion of the first number of suction cups connected to a second portion of the number of legs;

applying the pressure to the second number of suction cups;

rotating a first leg in the first portion of the number of legs in a first direction around a first axis;

rotating a second leg in the second portion of the number of legs in a second direction about the first axis in which rotation of the first leg and the second leg causes rotation of the frame system about a second axis that is substantially perpendicular to a surface of the workpiece;

attracting the magnetic material of the workpiece with an electromagnetic unit associated with the first frame to aid in the attaching of the first frame to the workpiece, wherein a channel extending through the electromagnetic unit receives the end effector and allows the end effector to reach the surface of the workpiece when the electromagnetic unit attracts the magnetic material of the workpiece; and

performing the number of operations at the second location on the workpiece.

16. The method of claim **15**, further comprising determining, with a sensor system in communication with the controller, a location of the crawler assembly where the end effector performs at least one operation in the number of operations on the workpiece.

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